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EVALUATION OF GREENHOUSE GAS EMISSIONS IN THE CONTEXT OF A LOGISTIC PLATFORM

NADA GHARZOUZI
DÉPARTEMENT DE MATHÉMATIQUES ET DE GÉNIE INDUSTRIEL
ÉCOLE POLYTECHNIQUE DE MONTRÉAL

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EVALUATION OF GREENHOUSE GAS EMISSIONS IN THE CONTEXT OF A LOGISTIC PLATFORM

présenté par : GHARZOUZI Nada
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a été dûment accepté par le jury d'examen constitué de :

M. TRÉPANIER Martin, ing., Ph.D., président
M. BAPTISTE Pierre, ing., Doct., membre et directeur de recherche
M. ROBERT Benoît, ing., Ph.D., membre

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RÉSUMÉ

De nos jours, le développement durable et la protection de l'environnement sont au cœur des enjeux globaux. Les entreprises font désormais face à des pressions sociales et politiques les poussant à adopter des pratiques d'affaires environnementales et durables. Dans le cas d'une plate-forme logistique, aucune comparaison n'a encore été faite entre l'impact environnemental des différentes opérations qu'on y retrouve. Ce manque d'information ne permet pas aux dirigeants d'établir des stratégies environnementales éclairées.

Ce projet de recherche s'attaque spécifiquement à ce gap d'information en évaluant les émissions de gaz à effet de serre des principaux secteurs d'une plate-forme logistique, située à Montréal, au Canada. Ces secteurs incluent le transport de marchandises, entrant et sortant, le transport du personnel et l'exploitation du bâtiment.

Deux objectifs ont été atteints. Le premier fut, basé sur des hypothèses précises, de calculer les émissions de ces différents secteurs afin de pouvoir les dimensionner globalement et de les comparer entre eux. Les résultats démontrèrent que le transport de marchandises s'est avéré le secteur émettant le plus d'émission de gaz à effet de serre: 34.7% des émissions totales proviennent du transport sortant de marchandises et 28% du transport entrant. L'exploitation du bâtiment en génère 18.8% et le transport du personnel, 15.7%.

Le deuxième objectif fut d'estimer les réductions potentielles d'émissions au sein de ces secteurs en simulant différents scénarios. Concordant avec les conclusions de la revue de la littérature, l'adoption du transport ferroviaire s'avère l'avenue la plus prometteuse en termes de réduction d'impact environnemental au niveau du transport sortant, spécialement pour les trajets de longue distance. D'autres scénarios, tel que la promotion du covoiturage au sein des employés, la possibilité de travailler à distance ou encore l'implantation de projets d'optimisation en efficacité énergétique permettent des réductions moins importantes, mais toutefois non négligeables. Finalement, le partenariat avec des fournisseurs plus proches en termes de distances peut aboutir à des

réductions importantes en émissions, cependant une révision complète de l'infrastructure d'affaire de la chaine logistique d'une compagnie devra être nécessaire.

ABSTRACT

More and more, the theme of sustainability and protection of the environment is at the centre stage of global issues. Organizations are facing social and political pressures to move towards environmental sustainability in their practices. In the case of a logistic platform, there is a lack of information on the comparative environmental impact of its operations, which prevents managers from establishing educated environmental strategies.

This research project tackles this void of information by evaluating the greenhouse gas emissions of the main sectors of an existing logistic platform, located in Montreal, Canada. These sectors include the transportation of goods, both inbound and outbound, the transportation of personnel and the building's operations.

Two goals were achieved. The first one was to benchmark the emissions of these sectors in order to get a clear idea of the dimension of their impact, based on specific assumptions. Results showed that transportation of goods turned out to be the biggest generator of GHG, with 34.7% due to outbound transportation and 28% due to inbound transportation. The building's operation accounted for 18.8% of the total emissions whereas the transportation of personnel accounted for 15.7%.

The second goal was to estimate potential savings in GHG emissions for all these sectors by simulating different scenarios. Concurrent with findings in the literature review, the switch from road to rail transportation appeared to be the most promising avenue to reduce the environmental impact of outbound transportation of goods, especially for shipments over long distances. Although other scenarios, such as the promotion of carpooling among employees, the possibility of remote work or the implementation of energy efficiency projects for the building, resulted in less substantial savings, these are still not negligible. Finally, the use of closer suppliers can lead to great potential in reducing GHG emissions; however, this would require a review of the entire infrastructure of the supply chain of the company.

CONDENSÉ EN FRANÇAIS

La protection de l'environnement est devenue un défi des plus importants auquel fait face le monde d'aujourd'hui. Au niveau économique, les entreprises font désormais face à des pressions politiques et sociales les poussant à adopter des processus d'affaires durables, visant à diminuer leur impact environnemental. Cependant, peu d'information portant sur l'impact relatif des différentes opérations d'une entreprise donnée est disponible, ce qui empêche les comités de gestion d'établir des stratégies environnementales éclairées. Ce projet de recherche a pour but de faire d'une part, l'évaluation des gaz à effet de serre (GES) des différents secteurs d'une plate-forme logistique, situé à Montréal, Canada, incluant le transport des marchandises sortant et entrant, le transport du personnel ainsi que l'exploitation du bâtiment, et d'autre part, d'étudier différentes actions à prendre afin de réduire l'impact environnemental de chacun de ces secteurs.

La revue de littérature a permis de mettre en évidence certains faits et études portant sur les trois secteurs identifiés précédemment et d'exposer différentes méthodes de calculs d'émissions disponibles.

Au niveau du transport de marchandises, on a pu constater qu'au Canada, la croissance constante d'activité depuis les dix dernières années, a résulté à une augmentation d'émissions de GES de 26% entre 1998 et 2005. Le transport via poids lourds a augmenté de 105% entre ces dates, expliquant en grande partie l'augmentation des émissions de ce secteur (Natural Resources of Canada, 2007).

McKinnon (2003) identifie trois ratios ayant un impact direct sur l'environnement :

(i) *Ratio 1 = Tonnes-kilomètres total*, faisant référence à l'intensité de transport, c'est-à-dire au poids total de marchandises produit et distribué.

(ii) *Ratio 2 = Tonnes-kilomètres route*, faisant référence au poids de marchandise transporté par voie routière.

(iii)*Ratio 3 = Véhicules-kilomètres*, faisant référence à l'utilisation d'un véhicule, donc du nombre de véhicules nécessaire pour transporter un volume donné.

De nombreux facteurs impactent directement ces ratios, comme par exemple:

- Le choix de fournisseur locaux ou l'utilisation de système de planification routière permet de réduire les distances parcourues, donc de réduire les Ratios 1 et 2 et de minimiser les émissions de GES (Holzapfel, 1995; UK Departement for Transport, 2005).
- Le transfert vers des modes de transport plus environnementaux, tel que le transport ferroviaire, permet la réduction du Ratio 2 et par conséquent, des émissions de GES totales (Steenhof, Woudsma, & Sparling, 2006; Ramanathan, 2000).
- L'amélioration du taux de remplissage des véhicules permet de diminuer le nombre de camions sur les routes et donc de réduire le Ratio 3. De nombreuses stratégies sont évoquées dans la littérature : L'obtention d'une plus grande consolidation de marchandise peut se faire en utilisant des cycles de commandes plus efficaces, tel que le *Nominated Day Delivery Service*, en évitant le transport dédié ou encore en compartimentant l'espace d'une remorque par un double plancher (McKinnon A. C., 2003; Logistics & Transport Focus, 2003).

D'autres éléments plus techniques ont aussi un impact favorable sur l'environnement, comme par exemple le suivi régulier de la maintenance des camions utilisés (EPA, 2004).

Dans le cas du transport du personnel, on a pu constater que les émissions de GES générées sont parfois très importantes : Le cas de l'École Polytechnique de Montréal en est un exemple. Les émissions reliées au déplacement des étudiants et du personnel sont les plus importantes, surpassant de 39% celles liées à l'exploitation des différents bâtiments (Comité de Gestion Environnementale de Polytechnique, 2008). Plusieurs

stratégies ont déjà été implantées par certaines entreprises. La permission de faire du télétravail, la promotion du covoiturage ou encore le système de semaine compressée font parties des options citées (CBORD Inc., 2008; Morgan Cole Inc., 2008; Sun Microsystems Inc., 2008). L'usage du transport en commun permet aussi la réduction des GES, cependant, statistiquement parlant, la population active Canadienne favorise toujours l'automobile pour se rendre au travail. Les grandes villes ont une proportion plus élevée de personnes utilisant le transport publique; ceci est expliqué par le fait que le réseau de métro / bus est beaucoup plus développé qu'en région rurale. D'autres facteurs rentrent aussi en considération dans le choix de transport d'une personne : la distance entre sa résidence et son lieu de travail, son âge ou encore ses moyens financiers (Statistics Canada, 2008 a)).
Étant donné que la voiture reste le moyen de transport privilégié des Canadiens, la promotion de l'utilisation de véhicules hybrides permettra une réduction de GES dans ce secteur. Cependant, malgré les différents programmes gouvernementaux offerts pour favoriser leur achat, les véhicules hybrides sont en général plus chers à l'achat et n'offrent pas toujours les mêmes performances qu'une voiture conventionnelle (Fontarasa, Pistikopoulosa, & Samaras, 2008; Ewing & Sarigöllü, 1998).

Le dernier secteur considéré est celui relatif à l'exploitation du bâtiment de la plate-forme logistique. Au Canada, le secteur commercial et institutionnel comprend environ 440,000 bâtiments responsables de 14% de la consommation totale d'énergie. Les émissions en GES sont principalement causées par le chauffage des espaces: dans le domaine du transport et de l'entreposage, il est responsable de 63% des émissions de GES. La source d'énergie la plus utilisée pour chauffer reste le gaz naturel (OEE, 2007 b)). L'optimisation de la gestion de l'énergie au sein de bâtiment reste un élément essentiel et lucratif pour les compagnies. Pour des constructions existantes, plusieurs options s'offrent telles que l'utilisation de lumières efficaces, l'installation de panneaux solaires pour le chauffage de l'eau, l'amélioration de l'isolation de l'enveloppe du bâtiment, ou encore la centralisation des contrôles de ventilations (Witt, 2007; Yoders, 2006; Aker, 2008; DiBenedetto, 2008)

La dernière partie de la revue de littérature porte sur les différentes méthodes de calculs disponibles. Les GES connus ont différents impacts sur le réchauffement planétaire. Afin de pouvoir les comparer, on doit les transformer en CO_{2eq}. Pour cela, la communauté scientifique a établi une mesure appelée Potentiel de Réchauffement Planétaire (PRP). Par exemple, une tonne de méthane (CH_4) a un effet cumulatif sur 100 ans équivalent à 21 tonnes de CO_2 (Environment Canada, 2003). Toutes les méthodes de calculs permettent donc d'avoir un résultat en CO_{2eq}. Les PRP utilisés dans nos calculs sont listés ci-dessous.

GES	**Formule**	**Potentiel de Réchauffement Planétaire**
Dioxyde de Carbone	CO_2	1
Méthane	CH_4	21
Oxyde Nitreux	N_2O	310

Les méthodes de calculs sont divisées en deux catégories:

A. <u>Méthode applicable aux émissions générées par des sources de combustion stationnaire</u>.

Nous appliquerons cette méthode pour le calcul des émissions dues à l'exploitation du bâtiment. La formule est la suivante (IPCC, 2006) :

$$\text{Emissions}_{\text{GES,Energie}} = \text{Consommation d'énergie}_{\text{Energie}} * \text{Facteur d'émission}_{\text{GES,Energie}}$$

Avec:

- $\text{Emissions}_{\text{GES,Fuel}}$ = émissions du gaz par type d'énergie utilisé (kg GES)
- $\text{Consommation d'énergie}_{\text{Energie}}$ = Total d'énergie utilisée (TJ ou m^3 ou MWh)

- Facteur d'émission $_{GES,Energie}$ = Facteur d'émission d'un gaz émis par type d'énergie (kg gaz/TJ ou kg gaz/ m^3 ou kg gaz/MWh). Pour le CO_2, ceci inclue un PRP égal à 1.

Dans le cas sous étude, les émissions totales seront celles générées par la consommation de gaz naturel (données en m^3) additionnées à celles générées par la consommation d'électricité (données en MWh). Ce sont les deux seules sources d'énergie utilisées et la consommation annuelle pour chacune des sources d'énergie est obtenue grâce aux factures des fournisseurs d'énergie Gaz Metro et Hydro-Québec.

B. Méthode applicable aux émissions générées par des sources de combustion mobile.

(i) Dans le cas du transport du personnel, l'équation utilisée est (EPA, 2009) :

a. $E = VKP * (EF_{CO2} + EF_{CH4} * 21 + EF_{N2O} * 310)$ pour les employés voyageant en voiture

b. $E = PKP * (EF_{CO2} + EF_{CH4} * 21 + EF_{N2O} * 310)$ pour les employés voyageant en transport public

Avec:

- E = Émissions totales en CO_{2eq} (kg)
- VKP = véhicules-kilomètres parcourus
- PKP = Passagers-kilomètres parcourus
- EF_{CO2} = Facteur d'émission du CO_2 (kg/véhicule-km ou kg/passager-km)
- EF_{CH4} = Facteur d'émission du CH_4 (kg/véhicule-km ou kg/passager-km)
- EF_{N2O} = Facteur d'émission du N_2O (kg/véhicule-km ou kg/passager-km)
- 21 = Facteur de conversion pour rationaliser le PRP
- 310 = Facteur de conversion pour rationaliser le PRP

Les facteurs d'émissions utilisés sont:

Table 1: Facteurs d'émissions liés au transport du personnel (EPA, 2009)

	CO_2	CH_4	N_2O	$CO_{2,eq}$
Type de véhicule	(kg /véhicule-mile)	(g /véhicule-mile)	(g /véhicule-mile)	**(kg/véhicule-mile)**
Voiture régulière	0.364	0.031	0.032	**0.375**
Transport publique	(kg/passager-mile)	(g /passager-mile)	(g /passager-mile)	**(kg/passager-mile)**
Bus	0.107	0.0006	0.0005	**0.107**
Métro	0.163	0.004	0.002	**0.164**

Afin d'estimer les émissions de GES générées par le personnel voyageant entre le lieu de travail et la maison, les informations nécessaires sont (The GHG Protocol, 2009):

- Le nombre d'employés
- Le nombre de visiteurs quotidiens
- Le nombre de km parcouru par employé par jour
- Le type de transport utilisé
- Type de véhicule utilisé
- Nombre de jours travaillés

Nous avons réussi à obtenir du département des ressources humaines la liste de tous les employés et leurs adresses. Au total, 363 personnes travaillent sur trois quart de travail différents. La distance parcourue pour chacun de ces employés a été trouvée grâce au logiciel MapPoint2009. Les estimations qui ont été faites pour palier au manque d'information sont :

1) Aucun employé ne fait du covoiturage
2) 10 visiteurs sont invités quotidiennement sur le site et font 15km pour y arriver
3) 5% de la distance totale parcourue par les employés est faite via le transport public. On considérera que la moitié de cette distance est parcourue par bus et l'autre moitié par métro
4) L'année comprends 245jours ouvrables de travail
5) Aucun télétravail n'est fait

6) D'autres facteurs tels que les voyages d'affaires par avion et la congestion sur les routes ont été ignorés

Tous les calculs ont été basés sur le nombre de km parcourus. Nous avons fait varier dans un deuxième temps les hypothèses citées ci haut afin d'établir les gains potentiels en émissions. Par exemple :

- Si on estime 10jours de télétravail effectués par les employés de bureau, le calcul de distance parcourue sera effectué sur 235 jours travaillés sur le site.
- Si on estime que 10% du quart de travail de jour et de soir font du covoiturage, le calcul effectué prendra en compte que 10% de la distance parcourue sera fait par une voiture au lieu de deux
- Si on estime que 20% du personnel utilise les transports publics, le calcul effectué se basera sur le fait que 20% de la distance parcourue sera effectué par transport publique et 80% par voiture

(ii) Dans le cas du transport de marchandises, la méthode de calcul varie: elle peut être basée sur le poids de marchandises transportées, ou sur le nombre de véhicules-kilomètres. Les facteurs d'émissions sont donnés en kg/tonne-km ou en kg/véhicule-km. Selon le mode de transport, on observe que :

a. Pour le transport maritime ou ferroviaire, les facteurs d'émissions ne sont donnés qu'en termes de kg/tonne-km. L'équation utilisée sera donc (EPA, 2009):

$$E = TKP * (EF_{CO2} + EF_{CH4} * 21 + EF_{N2O} * 310)$$

Avec:

- E = Émissions totales en CO_{2eq} (kg)
- TKP = Tonnes-kilomètres parcourus
- EF_{CO2} = Facteur d'émission du CO_2 (kg/tonne-km)
- EF_{CH4} = Facteur d'émission du CH_4 (kg/tonne-km)
- EF_{N2O} = Facteur d'émission du N_2O (kg/tonne-km)
- 21 = Facteur de conversion pour rationaliser le PRP
- 310 = Facteur de conversion pour rationaliser le PRP

Les facteurs d'émissions utilisés sont :

Table 2: Facteurs d'émissions pour le mode maritime et ferroviaire (EPA, 2009)

	CO_2 (kg CO_2/tonne-mile)	CH_4 (g CH_4/tonne-mile)	N_2O (g N_2O/tonne-mile)	**CO_{2eq} (kg/tonne-mile)**
Transport de marchandises				
Mode Ferroviaire	0.0252	0.002	0.0006	**0.025**
Mode Maritime	0.048	0.0041	0.0014	**0.049**

b. Dans le cas du transport routier, le calcul peut se faire de deux façons : soit tel que décrit ci-dessus, soit basé sur le nombre de véhicules-km.

Afin de prendre en considération le taux de remplissage des camions, la méthode choisie est celle basée sur le nombre de véhicules-km. En effet, si l'on se fie aux poids de marchandises seulement, le résultat risque d'être mal estimé comme par exemple, dans le cas de produits de faible densité mais à gros volume. Basée sur la méthode présentée par l'ADEME (2007), l'équation sera :

$$E = V_{pl}KP * (EF_{CO2eq})$$

Avec:

- $V_{pl}KP$ = véhicules (poids lourds)-kilomètres parcourus
- EF_{CO2eq} = Facteur d'émission du CO_{2eq} (kg/véhicule-km) d'un véhicule chargé à 70% de sa capacité. L'ADEME considère que pour des véhicules de plus de 3.5t de capacité, le facteur d'émissions entre un véhicule à vide et un véhicule chargé à pleine capacité varie par un facteur de 1.44. En estimant une progression linéaire, on peut dire que :

  $EF_{CO2eq} = EF_{vide} + (1.44\ EF_{vide} - E_{vide}) * 70\%$

Les valeurs utilisées sont listées à la table ci-dessous :

Table 3: Facteurs d'émissions donnés par l'ADEME (2007)

	Moyenne	Véhicule à vide	Véhicule plein	Charge maximale
Type de véhicule – base sur leur capacité de charge maximale	**Kg CO_{2eq} par véhicule - km**	**Kg CO_{2eq} per véhicule - km**	**Kg CO_{2eq} per véhicule - km**	**(tonnes)**
11 à 19t (Camion de 24')	0.2613	0.208	0.3	9.79
21.1 à 32.6t (semi-remorque de 53')	0.372	0.302	0.435	16.66

Avec plus de 340,000 livraisons faites annuellement à plus de 8,000 clients différents, l'analyse du transport sortant s'est avéré un vrai défi. La typologie du transport sortant qui a été pris en compte est schématisée dans la figure ci-dessous.

A = Origine B = Point de détour C = Client

H1 = Premier hub de transbordement H2 = Deuxième hub de

Figure 1: Typologie du transport sortant

En général, une livraison part de la plate-forme logistique sous étude et est consolidée avec d'autres livraisons d'autres clients au transporteur sélectionné à la première plate-forme de transbordement du transporteur H_1. La consolidation se fait en général par destinations **(Phase 1).** Une fois consolidée, la livraison est chargé dans une remorque et parcours la distance d2 jusqu'à atteindre la deuxième plateforme de transbordement H_2 du transporteur, généralement situé dans un périmètre plus proche de la destination finale **(Phase 2).** Une fois à H2, la livraison est à nouveau consolidée avec des livraisons destinées vers la même région **(Phase 3).** d_4 représente la distance supplémentaire que doit effectuer le transporteur afin de livrer la commande d'un client spécifique qui ne se trouve pas sur sa route **(Détour)**.Par exemple, une livraison qui part pour Vancouver sera consolidée à H_1 avec d'autres livraisons pour l'ouest canadien, et sera à nouveau regroupé à H_2 avec des livraisons locales pour la région de Vancouver. Les distances d_1, d_2 et d_3 entre les différentes plates-formes ne sont pas connues.

Nous avons considéré trois types de clients :

1) Les clients réguliers : les livraisons pour ces clients incorporent toutes les étapes décrites ci-dessus
2) Les clients majeurs : les livraisons pour ces clients n'impliquent aucun détour supplémentaire vu qu'en général, ils font parties de la tournée du transporteur. Ce sont en général des grosses chaines de magasins.
3) Les distributeurs : Ces clients sont considérés comme H_2

Les hypothèses sur le type de véhicules utilisés par phase, les différentes distances et taux de remplissage utilisés sont listées dans le tableau ci-dessous.

Table 4: Hypothèses faites sur le transport sortant

				Distance sur chaque phase		
	Type de camions	Capacité	Taux de remplissage	Clients réguliers	Clients majeurs	Distributeurs
Phase 1	Semi-remorque 53'	3,800 pi^2	70%	10km	10km	10km
Phase 2	Semi-remorque 53'	3,800 pi^2	70%	90% de D	90% de D	100% D
Phase 3	Camion de 24'	1,500 pi^2	70%	10% de D	10% de D	0
Detour	Camion de 24'	1,500 pi^2	70%	2km	0	0

Grace à ces hypothèses, nous sommes parvenus à déterminer le nombre de véhicules équivalent par type (semi-remorque de 53' ou camion de 24'). Les données obtenues du système d'information de la plateforme logistique incluait l'adresse du client, le poids et le volume expédiés par jour. En estimant un taux de remplissage, on a pu obtenir, en divisant le volume total expédié par la capacité du véhicule considéré, le nombre de véhicules par client.

Sur les phases 2 et 3, on a multiplié ce nombre par la distance parcourue, ce qui nous a permis d'obtenir $V_{pl}KP$ pour chaque client sur chacune de ces phases.

Les émissions sur la phase 1 ont été obtenues différemment. Le nombre de remorque qui quitte la plateforme logistique sous étude a été estimée à l'aide de registres tenus par l'agent de sécurité du site. En effet, sur la phase 1, les livraisons sont consolidées par transporteur et non par destination. Un total de 9,040 camions quittant le site annuellement a été estimé, basé sur la compilation de données sur trois mois.

Nous avons considéré que toutes livraisons sortantes étaient faites par voie routière.

L'analyse du transport entrant est similaire sur la portion des livraisons faites par voie routière. Les 60 fournisseurs du site sous étude sont dispersés à travers le globe entre les USA, l'Europe et l'Asie et envoient près de 20,000 tonnes de marchandises annuellement.

La typologie du transport pour les fournisseurs d'Europe et d'Asie est décrite dans le schéma ci-dessous.

Figure 2: Typologie du transport entrant provenant d'Asie et d'Europe

Les émissions générées sur la partie maritime du transport sont calculé basé sur le poids de marchandises. Celles qui sont générées sur la partie routière du transport (Fournisseurs – Port et Port de Montréal – Site sous étude) sont calculées en prenant compte un taux de remplissage de 70% et l'utilisation d'une semi-remorque de 53', de la même façon que pour le transport sortant.

Les données obtenues du département de transport de la plate-forme logistique sous étude incluait entre autres:

- Le poids total de marchandises importées par fournisseurs
- L'adresse des fournisseurs

- La date de livraison

Les distances entre fournisseurs et le port, et entre les différents ports et celui de Montréal, ont été trouvées grâce à des sites web calculateurs de distances.
Les résultats basés sur les hypothèses initiales sont présentés à la Figure 3.

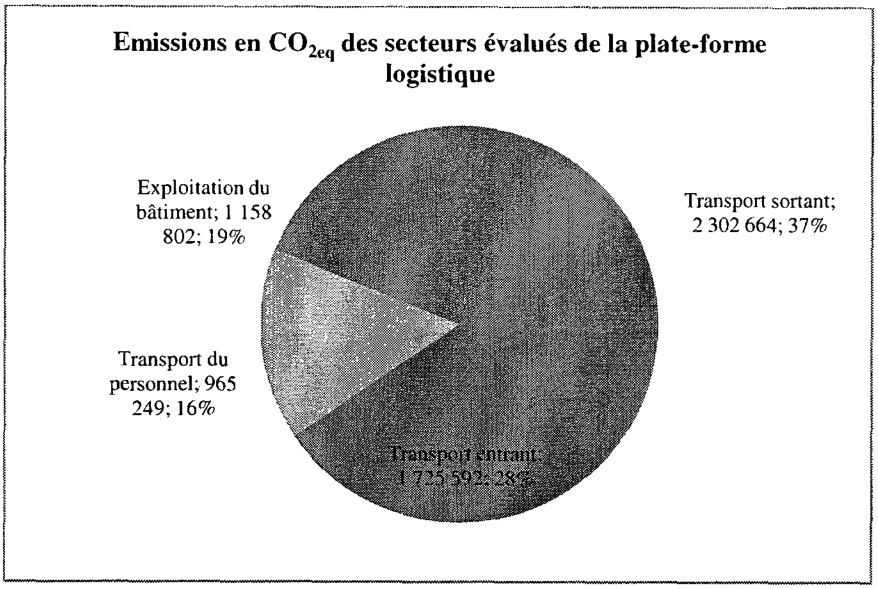

Figure 3: Émissions en kg de CO_{2eq} des secteurs évalués de la plate-forme logistique sous étude

Les principaux éléments à souligner sont :

- Au niveau du transport sortant :
    - 95% des émissions se font sur la Phase 2
    - 81% des émissions sont générées par les livraisons destinés à l'Alberta et la Colombie Britannique. Ces livraisons représentent 31% du volume expédié total.
    - 12% des émissions proviennent des livraisons faites en Ontario. Ces livraisons représentent 43% du volume expédié.
    - 1% des émissions proviennent des livraisons faites au Québec. Ces livraisons représentent 19% du volume total expédiés
- Au niveau du transport entrant:

    - 32.8% des émissions proviennent des importations américaines. Ces importations représentent 71% du volume total importé.
    - 38.9% des émissions proviennent des importations françaises. Ces importations représentent 18% du volume importé.
    - Le transport maritime génère 60% des émissions totales du transport entrant.
- Au niveau de l'exploitation du bâtiment:
    - 99% des émissions sont générées par l'utilisation du gaz naturel pour le chauffage.

Plusieurs scénarios ont, par la suite, été simulés en variant les hypothèses initiales. Le but de ces simulations était de valider les hypothèses faites, et de mesurer l'impact qu'auraient différentes stratégies que pourraient prendre le comité de direction de la plate-forme logistique sous étude.

Au niveau de la validation des hypothèses, on a pu remarquer que:

- Sur la Phase 1, les émissions ont été calculées basées sur un taux de remplissage de 70% et une distance d_1 de 10km. On a pu constater que:
    - Augmenter le taux de remplissage de 5% permet de réduire le nombre de camions de 603
    - Augmenter la distance d_1 à 15km augmente les émissions sur cette phase de 42%. Cependant, ceci représenterait 1.54% des émissions totales reliées au transport sortant.
- Sur la Phase 2 et 3, les émissions ont été calculées en considèrent d_2=90% de la distance total entre le site et le client (D) et d_3=10% de D:
    - Si d_2= D, les émissions totales du transport sortant diminueraient de 0.8%. La marge d'erreur lors de l'établissement des valeurs de d_2 et d_3 est donc faible.

- Sur la phase de détour, les émissions ont été calculées en considérant un détour juste pour les clients réguliers. On a pu constater que :
    - Si tous les clients imposaient un détour au transporteur, les émissions augmenteraient de 1,068kg de CO_{2eq}, ce qui représentent moins de 0.02% des émissions totales du transport sortant.
    - Si l'on augmente d_4 à 10km, à un taux de remplissage de 70%, les émissions seraient de 1521kg de CO_{2eq}, soit 0.7% des émissions totales du transport sortant.
    - Le détour peut être ignoré dans les calculs, vu que son impact est minime.

D'autres simulations ont été effectuées et les principaux résultats sont présentés dans la Table 5.

Table 5: Résultats des scénarios simulés et de leurs réductions potentielles en émissions

	Réduction potentielle (Tons of CO_{2eq})	% des émissions totales calculées initialement
Transport		
Entrant		
• Importer des États-Unis au lieu de la France	576	9.4%
Sortant		
• Augmenter de 5% le taux de remplissage pour les livraisons en Alberta et en Colombie Britannique	92.4	1.5%
• Augmenter de 5% le taux de remplissage pour toutes les livraisons	117.9	1.9%
• Utiliser le mode ferroviaire en Phase 2 pour les livraisons en Alberta et en Colombie Britannique	1,127.5	18.3%
Personnel		
• Avoir un taux de covoiturage de 5% pour le quart de nuit et de jour	13.8	0.2%
• Avoir un taux de covoiturage de 10% pour le quart de nuit et de jour	27.7	0.5%
• Avoir un taux de covoiturage de 20% pour le quart de nuit et de jour	55.4	0.9%
• Avoir un taux de covoiturage de 30% pour le quart de nuit et de jour	83.1	1.4%
• Permettre aux employés de bureau de faire du télétravail 30jours par année	51	0.8%
• Permettre aux employés de bureau de faire du télétravail 40jours par année	68	1.1%
• Avoir 20% des employés utilisant le transport public	94	1.5%
Exploitation du bâtiment		
• Optimiser le contrôle de la ventilation	457.2	7.4%
• Améliorer l'isolation de l'enveloppe du bâtiment	23	0.4%

Il est évident, à la vue des simulations, que l'avenue la plus prometteuse est l'utilisation du mode ferroviaire pour les destinations lointaines, tel que l'Alberta ou la Colombie Britannique. La possibilité d'utiliser le mode ferroviaire pour les livraisons en Ontario a été mentionnée dans la littérature (Patterson, Ewing, & Haider, 2008), cependant, elle n'a pas été évaluée dans le contexte de cette recherche. D'autres options s'avèrent intéressantes: l'implantation de projets d'efficacité énergétique sont non-seulement lucratifs pour une compagnie, mais permettent également une réduction substantielle des émissions de GES. Au niveau du transport du personnel, la promotion du covoiturage et la permission de faire du télétravail permettent également une réduction de l'impact environnemental global de la plate-forme logistique. La réduction est moins élevée que celle des avenues mentionnées précédemment, cependant, elle reste non-négligeable. Au niveau du transport entrant, le transfert de production de la France aux États-Unis permet de mettre en évidence que le fait d'avoir des fournisseurs plus proches permet une réduction importante des émissions. Cependant, un tel projet nécessite une révision complète de la structure de la chaine logistique, et tel que mentionné par McKinnon (2003), reste un projet financièrement non viable dans le cas d'une structure déjà existante.

D'autres options devraient être également analysées plus en profondeur. La structure du cycle de commande de la plate-forme logistique peut être optimisée par le biais de négociation avec les clients (Jackson, 1985; McKinnon A. C., 2003) : consolider les commandes par région par jour permettrait une amélioration des taux de remplissage des camions et donc aboutirait à une diminution des émissions associées.

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AB	Alberta
BC	British Columbia
CH_4	Methane
CIS	Commercial and Institutional Sector
CMA	Census metropolitan areas
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_{2eq}	Carbon dioxide equivalent
CUS	Company under Study
DC	Distribution Centre
FCG08	Fuel Consumption Guide 2008
GES	Gaz à Effet de Serre
GHG	Greenhouse Gas
H_2O	Water vapor
HFCs	Hydrofluorocarbons
HR	Human Resources
IPCC	Intergovernmental Panel on Climate Change
MB	Manitoba
N_2O	Nitrous Oxide
NB	New Brunswick
NF	Newfoundland
NMVOCs	Non-methane volatile organic
NOx	Nitrogen oxides
NS	Nova Scotia
NT	Northwest Territories
NU	Nunavut

OEE	Office of Energy Efficiency
ON	Ontario
PE	Prince-Edward Island
PFCs	Perfluorocarbons
QC	Quebec
SF_6	Sulphur hexafluoride
SK	Saskatchewan
SOx	Sulphur oxides
TWA	Transportation and Warehousing Activity
UNECE	United Nation Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
YT	Yukon Territory

LIST OF APPENDICES

CHAPTER 1 : INTRODUCTION

With global warming becoming a worldwide issue, businesses around the world need to develop sustainable policies in order to ensure environmentally friendly operations. It is undeniable that "going green" is no longer a fashionable statement: it has become a crucial requirement for companies to remain competitive, ethical and marketable. This shift in mentality requires management committees to review their business strategies and therefore to realign all their activities. These activities include a range of factors that impact not only operations in general but employees as well. One factor that seems to have played a part in fast-forwarding this shift is the increasing oil prices in the past five years.

In the context of a logistic platform, there is a lack of information available on the relative impact of its operations. This shortcoming prevents management committees from establishing clear and informed sustainable strategies and, therefore, priorities cannot be set correctly and resources and efforts may not be well allocated.

The company understudy is a multinational that distribute consumer products. With suppliers, and distribution centers located around the world, it has placed sustainable development at the forefront of its global operational, procurement and marketing strategies. This case analysis will focus on the Canadian operations only.

The purpose of this research paper is to estimate and compare the greenhouse gas (GHG) emissions of the main activities of the Canadian logistic platform (Figure 1-1). They will include GHG emissions caused by:

- The transportation of goods (inbound and outbound)
- The transportation of employees and visitors commuting to the site
- The building's energy consumption

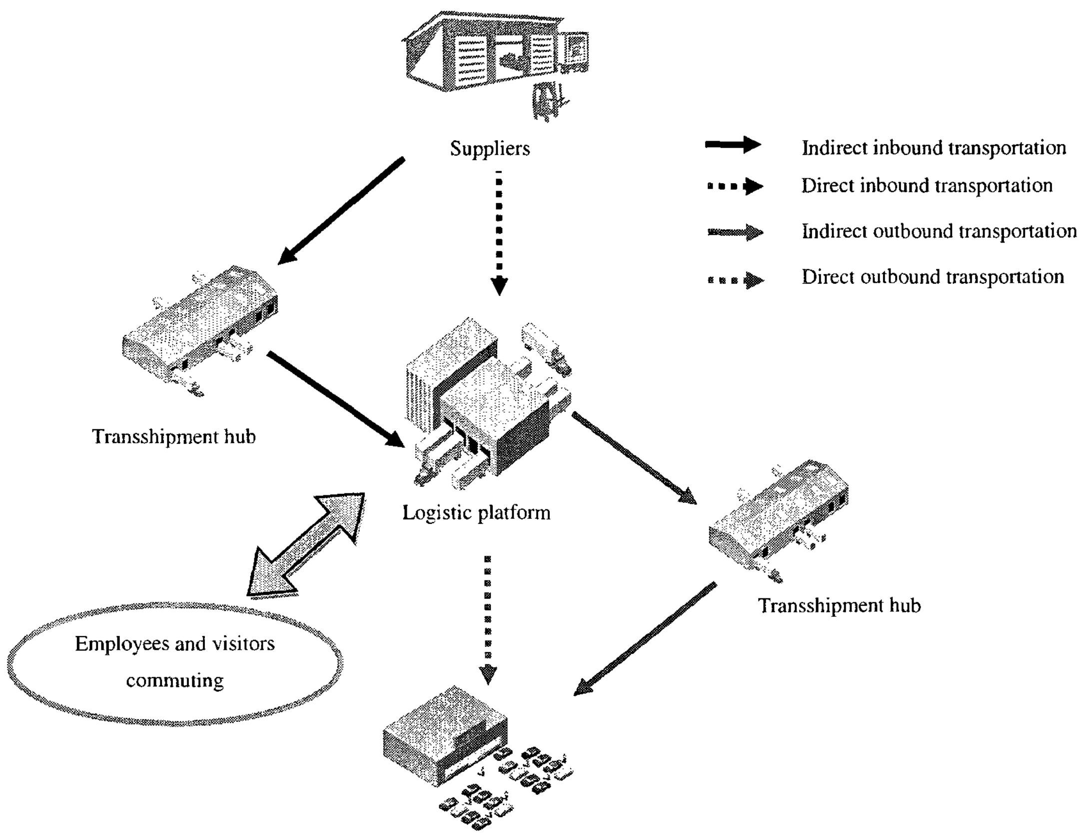


Figure 1-1: Various interactions in a logistic platform

Research revolving around optimization of transport in general has continuously challenged the way supply chains are structured: optimization is synonym to cost savings, but in many instances, it is also synonym to increased sustainability. As mentioned earlier, oil prices have been extremely volatile due to worldwide events. This has put tremendous pressures on transport professionals to offset this uncontrollable fuel surcharge with other ways to reduce their operational spending: switch to transport modes less energy consuming (hence less environmentally damaging) such as rail, attempt greater consolidation for better vehicle use or even negotiate alternative order scheduling with clients.

The discussion is not only applicable to transport of goods, but it is also applicable to transport of people. The oil price increases also affects employees that have to commute every day to their work sites. In their effort to be greener and to help their employees, some companies are taking advantage of the rise of new technologies to adopt new policies when it comes to their workforce such as allowing remote work. Programs to encourage carpooling with various perks are also becoming more popular. Also, governments are encouraging people to adopt more sustainable choices when it comes to their personal and professional travel.

The last aspect that we will consider in our comparative study is the building's GHG emissions. Buildings (commercial or institutional) account for about 14% of the total energy consumption in Canada. The environmental impact of construction has been an increasing concern for engineers and architect in the recent years. In the mid 90s, the emergence of the LEED (Leadership in Energy and Environmental Design) system has helped encourage and accelerate global adoption of sustainable green buildings[1]. Energy consumption in buildings is essential to ensure good work and/or living conditions for the people occupying it. Heating, lighting and cooling are some of the basics functions that we cannot eliminate, but that we should better control and manage in order to consume less.

This paper is divided as follows. First, we will present a literature review that will elaborate on what sustainability is, the Canadian facts on transport of goods and people, building consumption and their environmental impact. We will also present various researches that were done on the subject and analyze environmental strategies adopted by select companies. We will identify the data needed to be gathered for the purpose of this research and review existing analytical methods that will allow us to understand how to transform these data into GHG emissions. Second, we will present the methodology that we will use to reach our objective to estimate and compare the emissions of the identified sectors stated earlier. We will state what assumptions need to be made in order to reach that objective. Third, we will apply the presented methodology

[1] http://www.renewplaceriel.ca

to our case study. We will then discuss the results obtained by comparing them to results obtained in various scenarios that will be built by varying the assumptions made originally. This final exercise will allow us to first, get a rough idea on which actions could lead to the greatest savings in emissions and second, test the validity of the original assumptions made and the margin of error they can generate. We will end the report with a discussion and recommendations that can help management committees in their quest to make their business more sustainable.

CHAPTER 2 : LITERATURE REVIEW

2.1 Sustainable development – a brief introduction

In general terms, `sustainability' means working within three sets of constraints: techno-economic, environmental and social. Traditionally, engineering has been concerned with techno-economic issues. As always, engineers will need ingenuity, but they will need to deploy it with a new kind of social sensitivity: they need to innovate with the underlying objective to create technologies or practices that are sustainable (Clift, 1998). In the same sense, managers need to construct environmental policies that support sustainable ingenuity and business practices.

Canada signed the Kyoto Protocol on April 29, 1998, but the act became legally binding in early 2005. Under the terms of the Protocol, Canada is required to reduce emissions to a level of 6% below 1990 levels in the period 2008-2012 (Environment Canada, 2006). As a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), Canada is required to prepare a yearly emissions inventory. The Industry sector accounts for about half of Canada's greenhouse gas emissions that cause climate change (Environment Canada, 2007 a)): Facilities with direct emissions of over 100 kilotons of CO_{2eq} are required to submit a yearly report to the government (Government of Canada, 2008 b)). A logistic platform is not likely to surpass this threshold. However, if one accounts its indirect emissions, such as transportation of goods, use of energy or employees commuting, the total emissions could surpass the 100kilotons benchmark. For this reason, it is important to define the notion of scope (Figure 2-1).

Three scopes are defined to help delineate direct and indirect emission sources, and avoid duplicate counting of the same emissions (The GHG Protocol, 2003):

1. Scope 1: Direct GHG emissions:

Scope 1 accounts for direct GHG emissions that occur from sources that are owned or controlled by the company, for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment.

2. Scope 2: Electricity indirect GHG emissions

Scope 2 accounts for GHG emissions from the generation of purchased electricity consumed by the company. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. Scope 2 emissions physically occur at the facility where electricity is generated.

3. Scope 3: Other indirect GHG emissions

Scope 3 is an optional reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company. Examples of scope 3 activities are extraction and production of purchased materials, transportation of purchased fuels and use of sold products and services.

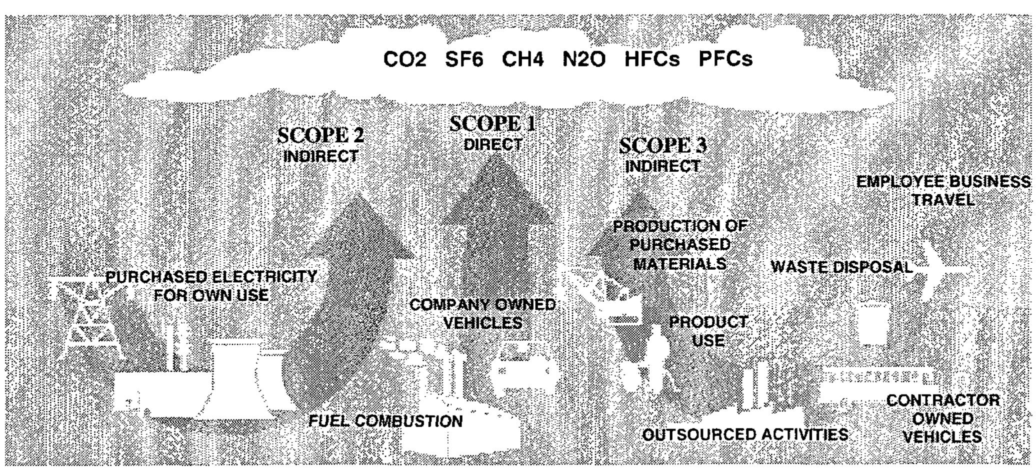


Figure 2-1: Overview of scopes and emissions across a value chain (Putt del Pino, Levinson, & Larsen, 2006)

Figure 2-3 shows that 38% of the energy use in Canada is within the industrial sector. A logistic platform includes three of the identified sectors:

1. The commercial, i.e. the distribution center,
2. The transportation freight, i.e. shipping and receiving activities
3. The transportation of passengers, i.e. employees commuting.

However, emissions related to these sectors are considered scope 2 and scope 3 emissions.

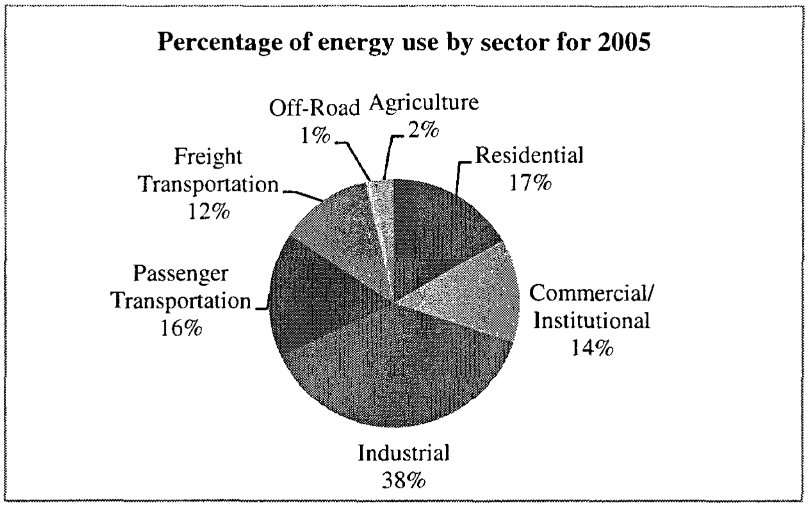


Figure 2-3: Percentage of energy use by sector (OEE, 2007 a))

Even though optional, scope 3 emissions can be very important, depending on the type of business considered. For example, IKEA, a global home furnishings retailer, has 82% of its total emissions accounted in scope 3: Customers travelling to the IKEA stores represents 56% of total emissions. Consequently, IKEA set and has met its goal of making at least 75% of its stores accessible by public transit. IKEA located its stores closer to cities and transit lines as well as funded transit projects near its stores. Another interesting example is DHL Express Nordic, a logistics and package delivery service operating in four Nordic countries. Although the company operates its own fleet of trains, trucks, ships, and planes, most of its deliveries are made by third-party contractors, and the resulting emissions are scope 3 for the company. These services are essential to DHL Nordic's business and account for 94% of its total GHG emissions. To reduce these emissions, DHL Express Nordic collects, through mandatory surveys, information about its contractors' environmental performance, including activity data such as fuel type, fuel usage, engine class, loading capacity and loading factors. Each contractor's performance receives a score, and since DHL Nordic Express works with only those contractors receiving scores above a certain number. Hence, contractors have an incentive to improve and maintain their environmental performance (Putt del Pino, Levinson, & Larsen, 2006).

Table 2-1: Example of businesses with high scope 3 emissions (Putt del Pino, Levinson, & Larsen, 2006)

IKEA'S AND DHL EXPRESS NORDIC'S 2004 GHG EMISSIONS (metric tons CO_2)				
Company	Scope 1	Scope 2	Scope 3	Total
IKEA	80,692 (3%)	421,142 (15%)	2,306,592 (82%)	2,808,424 (100%)
DHL Express Nordic	25,447 (5%)	4,969 (1%)	440,095 (94%)	470,511 (100%)

The purpose of this research is to evaluate the total CO_{2eq} emissions of a logistic platform. Identifying and estimating emissions in all scopes will allow management to modify their operations and develop environmental strategies for their businesses. In order to establish the elements needed for such evaluation, the literature review done in the following section will cover all three identified sectors, namely the transportation of goods, the transportation of personnel and the building operations and address the various calculation methods available to estimate GHG emissions for mobile and stationary combustions.

2.2 Transportation

Transportation, whether it is of the personnel or of the goods, is, in the case of a logistic platform, considered as scope 3 if all activities are subcontracted. Even if these emissions are not owned by a company, measuring them is essential in establishing environmental objectives, as seen in the case of IKEA or DHL Express Nordic.

Transportation fulfils an essential role in maintaining in a country's economic and social well-being. In 2005, the transportation sector accounted for approximately 26 percent of related greenhouse gas (GHG) emissions in Canada, making it the second largest emission-producing category. It also accounts for 32% of Canada's emission growth from 1990 to 2005. As shown in Table 2-2, road transportation accounts for 67.5% of GHG emissions while rail transportations accounts for only 3%. From 1990 to 2005, GHG emissions from transport, driven primarily by energy used for personal transportation, rose 33%, or 49 Mt. (Environment Canada, 2007 b)).

Table 2-2 : GHG Emissions from Transport, 1990-2005 (OEE, 2007 a))

	GHG Emissions *(kt CO_{2eq})*			
GHG Source Category	**1990**	**2004**	**2005**	**% of 2005**
Transport TOTAL (1.A.3)	**150,000**	**190,000**	**200,000**	**100.0%**
Civil Aviation (Domestic Aviation)	**6,400**	**7,900**	**8,700**	**4.4%**
Road Transportation	**101,000**	**133,000**	**135,000**	**67.5%**
Light-Duty Gasoline Vehicles	47,200	42,400	41,200	**20.6%**
Light-Duty Gasoline Trucks	21,300	43,300	44,500	**22.3%**
Heavy-Duty Gasoline Vehicles	8,050	6,600	6,510	**3.3%**
Motorcycles	151	252	260	**0.1%**
Light-Duty Diesel Vehicles	363	441	443	**0.2%**
Light-Duty Diesel Trucks	724	2040	2200	**1.1%**
Heavy-Duty Diesel Vehicles	21,200	37,400	39,000	**19.5%**
Propane & Natural Gas Vehicles	2,200	860	720	**0.4%**
Railways	**7,000**	**6,000**	**6,000**	**3.0%**
Navigation (Domestic Marine)	**5,100**	**6,700**	**6,500**	**3.3%**
Other Transportation	**30,000**	**40,000**	**40,000**	**20.0%**
Off-Road Diesel	20,000	20,000	20,000	**10.0%**
Off-Road Gasoline	7,000	8,000	7,000	**3.5%**
Pipelines	6,900	8,520	10,100	**5.1%**

When comparing both passenger and freight transportation, it is found that in 2005, 55% of the energy used was for passenger transportation, whereas 41% was used for freight transportation (Natural Resources of Canada, 2007), as shown in Figure 2-4.

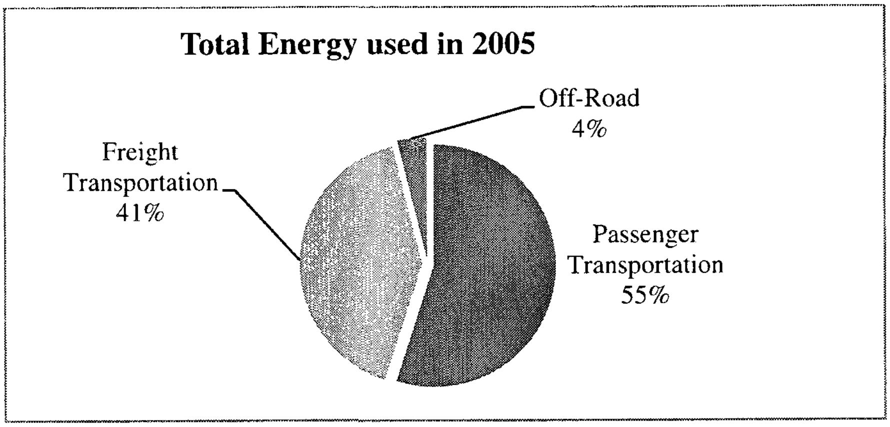


Figure 2-4: Total Energy used in 2005, comparing passenger freight and off road transportation

In the context of a logistic platform, freight and passenger transportation were never benchmarked against each other. What should management prioritize in order to be greener? Promoting sustainable transport for its employees or for its freight shipments? This literature revue will help narrow down the elements needed in order to measure both GHG emissions of daily commercial shipping and receiving as well as employees' commute between work and home.

2.2.1 Freight Transportation

2.2.1.1 *Canadian overview of freight transportation*

With its high environmental impact, freight transportation has been the focus of numerous governmental programs such as the US EPA's SmartWay[sm] Transport Partnership and the Canada's ecoFreight program. Freight transportation in Canada has been in constant growth for the past decade, with an increase in activity of 28% from

1998 to 2005, resulting in increasing CO_{2eq} emissions of 22.6% within that period, as shown in Figure 2-5.

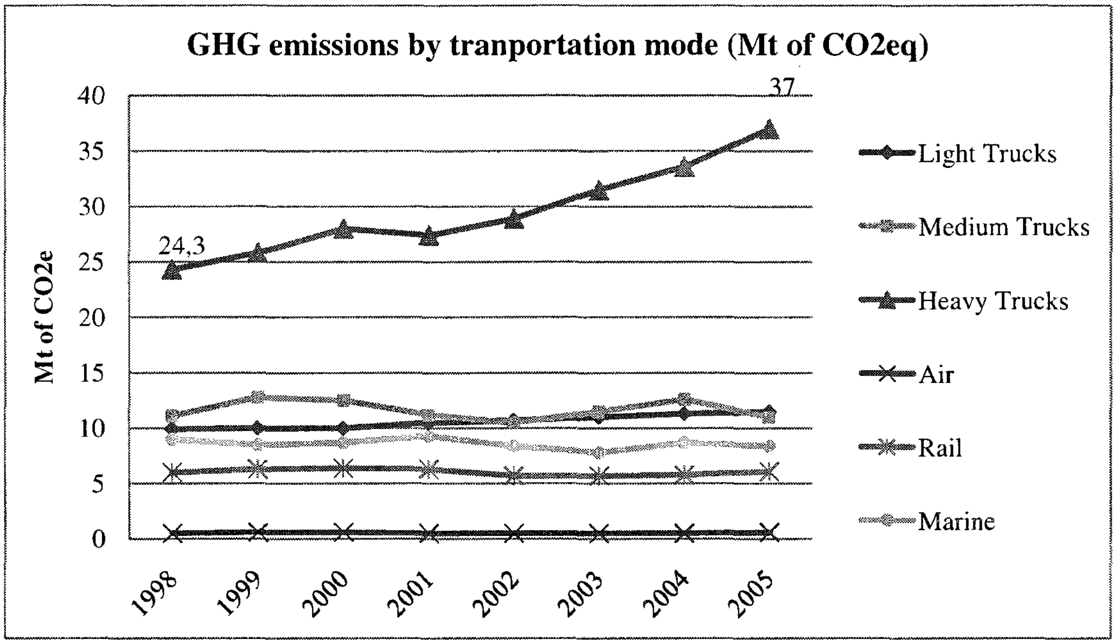


Figure 2-5: GHG Emissions by Transportation Mode (Mt of CO_{2eq}) (Natural Resources Canada, 2007)

As seen in Table 2-3, diesel fuel oil, with 53.2 Mt of CO_{2eq}, and motor gasoline, with 15.6Mt of CO_{2eq}, are the two sources of energy with largest GHG emissions in this sector.

Table 2-3: GHG Emissions by Energy Source (Mt of CO_{2eq}) (Natural Resources Canada, 2007)

	GHG Emissions by Energy Source (Mt of CO_{2eq})							
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Total Freight transportation	**60.9**	**64.0**	**66.2**	**65.2**	**64.7**	**68.0**	**72.6**	**74.5**
Natural Gas	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Motor Gasoline	14.1	15.9	16.0	14.8	14.6	15.2	16.0	15.6
Diesel Fuel Oil	40.0	42.1	44.2	43.8	44.5	47.1	50.6	53.2
Light Fuel Oil and Kerosene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heavy Fuel Oil	5.5	4.8	5.0	5.7	4.7	4.9	5.1	4.9
Aviation Gasoline	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aviation Turbo Fuel	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.5
Propane	0.7	0.6	0.4	0.5	0.3	0.3	0.3	0.3

Diesel Fuel oil is used in various mode of transport and is the only fuel used by heavy trucks and rail transportation. In 2005, 70.8% of the total Diesel Fuel used was by Heavy trucks, compared with 57.7% in 1995 (Table 2-4).

Table 2-4: Percentage of total Diesel Fuel used by different modes of transport (Natural Resources Canada, 2007)

	1995	2000	2005
Heavy trucks	57.7%	64.9%	70.8%
Medium trucks	16.5%	13.5%	12.3%
Light trucks	0.6%	0.5%	0.3%
Marine	9.2%	7.7%	6.0%
Rail	16.0%	13.4%	10.5%

The activities of Heavy Trucks in Canada also increased by 105% in the last 10 years, compared to other mode of transportation, with energy use increasing by 81% since 1995.

Table 2-5 : Comparison between activity and energy use of different modes of transport (Natural Resources Canada, 2007)

	Ton-Km (millions)			Increase since 1995	Energy Use (PJ)			Increase since 1995
	1995	**2000**	**2005**		**1995**	**2000**	**2005**	
Light trucks	13,814	17,433	21,007	52%	114.44	142.92	163.99	43%
Medium trucks	19,757	22,611	20,609	4%	165.80	177.67	155.65	-6%
Heavy trucks	110,000	164,720	225,645	105%	283.32	388.67	513.32	81%
Marine	189,050	210,057	241,400	28%	7.25	8.00	7.87	9%
Rail	280,426	319,769	355,652	27%	78.46	80.21	76.35	-3%
Aviation	2,045	2,327	2,283	12%	101.74	113.99	111.15	9%

GHG emission are still growing despite the rise of clean technologies and improvement of fuel efficiency, however air pollution emissions, such as fine particulate matter, sulphur oxides, nitrogen oxides and volatile organic compounds, have shown a steady decline due to regulatory initiatives and stock turnover (Transport Canada, 2007). Studies showed that if all factors in freight transport activity and modal shares remained equivalent to 1990, freight transport emissions would have been 65% higher today. Technological advances led to increase in fuel efficiency allowing the reduction of these emissions. Driver training programs, friction reduction as well as hybrid fuel technology in rail, use of natural gas engine for medium and heavy trucks as well as high pressure direct injection (HPDI) allowing the use of liquefied gas fuel for heavy duty trucks are among today's fuel efficiency solutions (Steenhof, Woudsma, & Sparling, 2006).

2.2.1.2 *Reducing the environmental impact of freight transport "at the source" in an operational context*

Decisions affecting freight transport operations can be divided into four categories (McKinnon A. C., 2003):

1. Strategic decisions relating to numbers, locations, and capacity of factories, warehouses, shops and terminals – hence determining the physical "infrastructure" of the business
2. Commercial decisions on product sourcing, the subcontracting of production processes and distribution of finished goods – hence establishing the pattern of trading links between the company and its suppliers, distributors and customers
3. Operational decisions on the scheduling of production and distribution that translate the trading links into discrete freight flows
4. Tactical decisions relating to the management of transport resources: within the framework defined by decisions at the previous three levels, transport managers have discretion over the choice, routing and loading of vehicles

McKinnon (2003) identifies three critical ratios that have a direct impact on the environment:

1. **Total ton-kilometers**: output - transport intensity. This ratio relates to the weight of goods produced and distributed.

2. **Road ton-kilometers**: total ton-kilometers – modal split. This ratio is expressed in terms of the split between road and other less environmentally damaging modes
3. **Vehicle-kilometers**: ton-kilometers – vehicle utilization. This ratio determines the amount of vehicle traffic required to handle a given volume of freight movement. It is influenced by the capacity of the vehicle, the average load carried on loaded trips and the proportion of vehicle-kilometer run empty.

These ratios will be a key element in our calculation method and will be explained in greater details in following sub-sections.

(i) *The Total ton-kilometer ratio: reducing transport intensity*

"Green logistics" measures are often introduced at the lowest level in hierarchy, but they are often offset by higher level decisions, such as centralization warehousing, choice of distant suppliers, or just-in-time replenishment, which often increase total vehicle - kilometers. Increasing haul lengths have been the main cause of road freight growth: in Europe, over the last 30 years, they have been responsible for two thirds of the increase in road ton – kilometers (McKinnon A. C., 2003). This increase can be attributed to:

- Wider spread suppliers, around the world that can offer better product mix: When talking about inbound transportation, choosing suppliers that are located in the same region can reduce total kilometers travelled dramatically. Holzafpel (1995) showed that, in the case of a pot of strawberry yogurt, if the closest supplier was chosen at each step of the production and distribution of the product, a 67% reduction could be reach in road ton - kilometers.

- Centralized production or warehousing, strategy that allows to cut the amount of safety stock by two third, but increase average distances from supply point to customer. In a simulation done by McKinnon (1998), transport cost would have to increase by 100% to make it economically beneficial to move to a more decentralized structure. Therefore, when discussing the case of an existing infrastructure, the decentralization option is not viable financially.

- Development of hub-satellites systems, that allows better consolidation and vehicle utilization, hence decrease traffic congestions levels, but increase haul length since more indirect routing is implied (McKinnon A. C., 1998). Location of hubs can be carefully chosen to minimize unnecessary traveling.

Using computerized load and route planning software, scheduling freight delivery times to avoid traffic and congestion or avoiding empty runs are additional strategies to cut emissions and improve total ton-kilometers ratio (Greater Vancouver Regional District, 2007). The use of such software is part of tactical strategies that are more easily implemented than modifying a company's entire business infrastructure. It can decrease distance travelled by 5-10%, though instances of 20% distance savings are quoted in the literature (UK Departement for Transport, 2005).

(ii) *The Road ton-kilometer ratio: Transferring freight to less environmentally damaging modes*

Shifting from truck to rail or from rail to marine, or even using freight vehicles that uses alternative energy are additional ways to decrease GHG emissions (Greater Vancouver Regional District, 2007). Rail is almost 15 times less energy intensive that trucks in general, and about 11 times less energy intensive than Heavy trucks (Figure 2-6).

Extensive related scientific research has been done on the evaluation and ways to quantify and foresee GHG emissions related to surface transport and the difference between environmental impacts between rail and road transportation. Several of them identified modal shift as the most promising method of reducing energy consumption of road freight transport (McKinnon A. C., 2003).

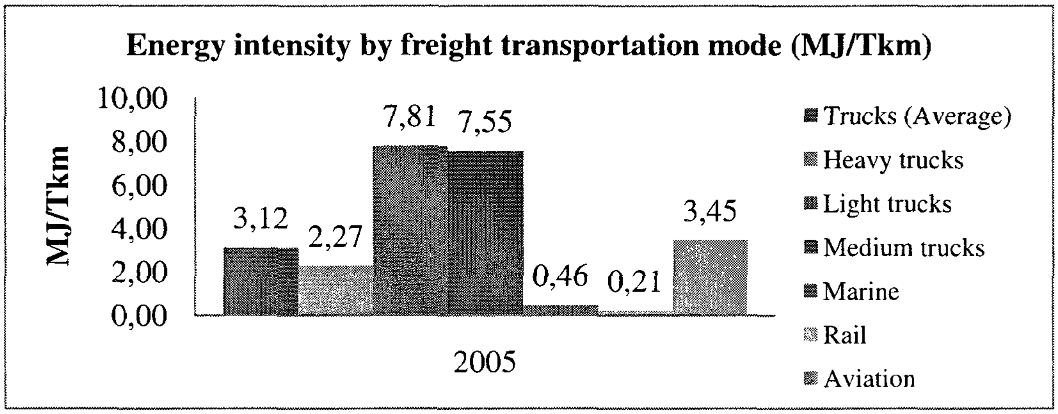


Figure 2-6: Energy Intensity in MJ/Tkm, by mode of freight transportation in 2005 (OEE, 2007 c))

Studies using holistic approaches to compare energy efficiencies between rail and road transport highlight huge savings in energy consumption (hence in CO_{2eq} emissions) if rail transport is made to capture future transport requirements (Ramanathan, 2000)

In the same mindset, Steenhof et al. (2006) showed that between 1990 and 2003, freight emissions increased by 140%, explained by changes towards modal shares toward truck-based transport (explained by the rise in Just-time delivery and increase import and export with the US following the Free Trade Agreement in 1989). Three scenarios are evaluated assuming different shares of rail and truck use, while including other factors such as increasing efficiency gains in the trucking industry and increasing fuel costs. The study showed that the highest energy and fuel cost savings are reached when rail is the most intensely used.

Pattersona, Ewing, & Haider (2008) evaluated the potential reduction in freight CO_2 emissions in the Quebec-Windsor corridor if a shift to premium-intermodal services is used. With 40% of the Canadian population located in this area, this corridor is the busiest trade and transportation corridor in the country. The focus of this study is on intermodal transportation that could compete directly with truck-only transportation in the corridor. The only one with such capabilities is the Premium-TOFC intermodal configuration: It prioritizes on-time reliability (controlled schedules and short unloading and loading times), minimizes damage risk by using smooth ride technologies and provides schedules that allow carriers to provide the same service to clients as their truck only services. In Canada, only CP rail offers such service: it is called the Expressway, and it offers rail service between Montreal and Toronto. The simulation results showed that the use of such intermodal services can allow a 16% reduction in CO_2 emissions compared to truck-only services.

Intermodal is an attractive option for shipments over 500 miles. The economic and environmental benefits of intermodal ground freight service are maximized over long hauls, where the fuel and cost savings from the rail part of the trip are high enough to recoup the extra fuel and handling costs to transport and transfer trailers and containers between trains and trucks. For shipments over 1,000 miles, using intermodal transport cuts fuel use and greenhouse gas emissions by 65 percent, relative to truck transport, alone. However, the challenges that intermodal transportation faces are fewer capabilities to bring freight "door-to-door" and have more limited scheduling flexibility than trucks. The characteristic swaying motion of train cars may harm certain damage-sensitive freight. Because of these distinctions, trucks are more extensively used (EPA, 2004). Various surveys were done to identify what influences the shipper's choice of transport mode. Cut-off attributes vary depending on factors such as type of goods shipped, time-sensitivity, and frequency of service. Some surveys suggest there is no obvious bias from shippers toward intermodal transportation (Danielis & Marcucci, 2007) whereas others claim that a 20% increase in the price truck-only shipment would be required to overcome the effect of shipper bias against intermodal shipping – a conclusion with challenging policy implications (Patterson, Ewing, & Haider, 2008).

Even if the most optimistic projections of a freight modal shift were to materialize, road would remain by far the dominant mode in most developed countries, due to lack of rail connections, specially for short distances. Rationalizing the road freight system by making more efficient route planning and use of vehicle capacity is the solution to investigate (McKinnon A. C., 2003).

(iii)*The Vehicle-kilometers ratio: improving vehicle utilization*

Empty running is the most obvious form of vehicle under-utilization. Efficient loading leads to environmental benefits. In vast geographical distribution of population, it is easier to balance loading of vehicles. Proportions of vehicle – kilometers run empty has been gradually declining in some countries, such as the UK, due to improvement in backloading strategies, online exchange of information and the growth in return of packaging for recycling and reuse (McKinnon A. C., 2003).

In Canada, almost one third of the trucks on the highway are still running empty (Nix, 2003). Between 2001 and 2003, the increase in truck weight limit from 41 to 44tonnes in the UK allowed a reduction of 134 million vehicle-km, which translates to 135700 ton of CO_2 emissions avoided (McKinnon A. C., 2005). However, for product of lower density, only volumetric measures of "vehicle fill" can give a true indication of the scope to improved loading. According to some studies, cube utilization averages out to 28%: loss in space occurs mainly in the vertical dimension with load heights averaging to about 47% of the maximum height (Samuelsson & Tilanus, 1997) . In 2002, another survey of 53 fleets in the UK food sector, comprising roughly 3,600 vehicles, found that on loaded trips an average 69% of the deck area and 76% of available height were utilized, corresponding to a mean cube utilization of 52%: On the average height of pallet loads, goods were stacked to an average height of 1.5-1.7 meters on 67% of the loaded journey legs. This corresponds to the typical slot height in warehouse racking across the food supply chain. On 9% of the loaded trips, average heights fell below 0.8 meters (Figure 2-7). On 41% of loaded journey legs, and for 27% of the total distance travelled laden, vehicles were less than half full when measured by deck area utilization (McKinnon, Ge, & Leuchars, 2003).

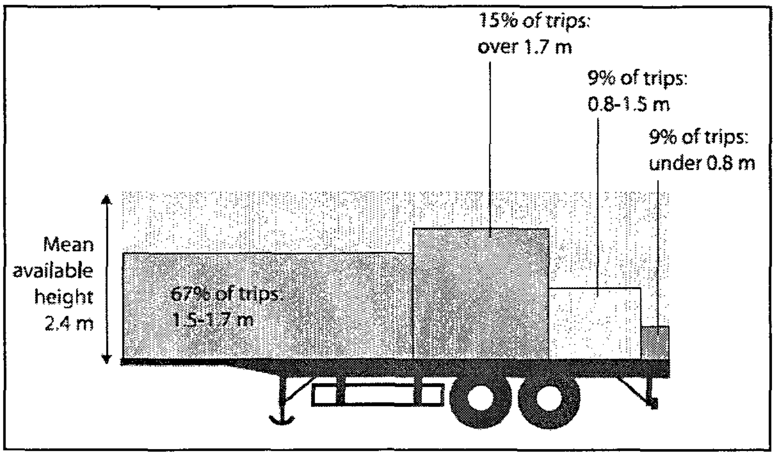


Figure 2-7: Percentage of trips with different heights of pallet-loads (McKinnon, Ge, & Leuchars, 2003)

The range of measures can be used to improve vehicle loading and they can be classified under four categories (McKinnon A. C., 2003):

1. Order fulfillment

Operational decisions on the scheduling of production and distribution operations translate business transactions into discrete vehicle movements. These schedules should allow flexibility in order to allow order consolidation so that a vehicle is loaded to full capacity. A survey showed that the main reason why companies practice consolidation is to reduce cost related to inventory and mostly transport. However, the main disadvantage mentioned was that consolidation implied longer order cycles, specially for rush orders. Consolidation systems are complex to develop. They must take into account a wide range of data, such as transport rates and disparities between parcel, LTL and TL shipping, customers 'specifications (for example: use of a specific carrier), weight or/and volume limits, lack of volume to ship, lack of planning time or products' sensitivity to time of delivery. Other issues include education of sales force or customers, as they often equate consolidation with delay (Jackson, 1985). Just-In-Time deliveries have unquestionably reduced average consignment weight in some sectors. In the absence of JIT pressures, there would probably have been a higher degree of load consolidation and possibly an increase in average load factors. The adoption of more transport-efficient order cycles, such as the *Nominated Day Delivery System (NDDS)* can help increase the degree of load consolidation, and hence reduce truck traffic levels. Firms operating this system achieve much higher levels of transport efficiency by encouraging customers to adhere to an ordering and delivery timetable. Customers are informed that a vehicle will visit their area on a "nominated" day, and that to receive a delivery on that day, they must submit their order a certain period in advance. The advertised order lead time is thus conditional on the customer complying with the order schedule. By concentrating deliveries in particular areas on particular days, suppliers can achieve higher levels of load consolidation, drop density and vehicle utilization. Some managers reject this system on the grounds that it would weaken their company's competitive position, and probably result in sales losses in excess of the transport cost savings. The experience of many of the businesses that have applied NDDS contradicts this view (McKinnon A. C., 2000).

2. Shared distribution

During the 1980s and 1990s, there was a sharp increase in the proportion of road haulage services provided on a dedicated basis for individual clients.

Dedication of services denies carriers the opportunity to perform their traditional "groupage" role and, as a result, carries a vehicle utilization penalty. However, there is evidence that in several European countries major users of dedicated services have been granting contractors the freedom to carry other firms' traffic in their vehicles. In the UK, several company-sponsored studies of the potential benefits of shared-user services in the automotive, consumer electrical and clothing sectors (in each case replacing four or five separate dedicated services) have indicated that this can reduce truck-kilometers by around 20% (McKinnon A. C., 2000).

3. Vehicle design

It is generally acknowledged that the average density and "stackability" of freight are declining. The major reasons for this decline can be summed up to (McKinnon A. C., Sustainable distribution: opportunities to improve vehicle loading, 2000):

- *Change in the nature of the products:* Many consumer products have become lighter over time, as plastic and other synthetic materials have increasingly replaced metal, wood and leather. Miniaturization of components has also reduced the weight of many appliances. A new generation of products has emerged in sectors such as electronics, sports equipment, toys and do-it-yourself (DYI) that are intrinsically of low density.
- *Increased packaging.* The move to self-service retailing, the growth of processed foods, and more intensive use of packaging as an advertising medium have greatly increased the amount of packaging. Many of the new electrical and electronic products are also very fragile, requiring thicker layers of protective packaging. As this packaging is very light, increases in the ratio of packaging volume to product volume reduce the average density of freight consignments.
- *Greater use of unitized handling equipment:* The growth of "palletization", and increased use of roll/cage pallets, has enabled firms to improve the efficiency of handling operations at the expense of vehicle utilization. This handling equipment takes up space in the vehicle, and again reduces average weight/volume ratio for the overall payload.
- *Declining "stackability".* In some sectors, the increasing fragility of the product (and weakening of packaging material) is limiting the height to which it can be stacked. In the food and drink industry, cans have become thinner and rigid cardboard, plastic, or even wooden boxes been replaced by cardboard trays which offer little vertical support.
- *Order-picking of palletized loads at an earlier stage in the supply chain:* Traditionally, distribution of manufactured products from the factory to the customer's warehouse was supply-driven, with pallets loaded to maximum height with a single product line and standard packaging. The flow of products at the upper levels of the supply chain is now becoming demand-driven, forcing manufacturers to assemble mixed orders for individual retail and wholesale

customers. Pallet loads of mixed products tend to be lower, have an irregular profile, and offer less opportunity for stacking.

- *Tightening health and safety regulation:* These regulations have restricted the height to which pallets can be stacked during loading and unloading. This, too, has the effect of reducing the amount of freight that can be carried on each square meter of vehicle deck area.

Truck dimensions are constrained by the geometry of road layouts, bridge heights and loading bays, and by the height of bridges and tunnels. Where the transport infrastructure permits an increase in vehicle height, the insertion of an extra deck could allow firms to make more effective use of vehicle space: double deck (or even triple deck) trailers can also allow stacking of pallets, regardless of their shape or strength, up to the weight limit (Logistics & Transport Focus, 2003; McKinnon & Campbell, 1997). It is perfectly suitable for light products. Vehicles can also be redesigned in other ways to permit greater load consolidation. Compartmentalization of trucks has enabled grocery retailers and their contractors to combine the movement of products at different temperatures on a single journey.

4. Space efficiency of handling equipment and transit packaging

Average deck area utilization can vary between 52 and 78%, depending on the dimension of wooden pallets. The efficiency with which a vehicle's cubic capacity is used partly depends on the nature of the packaging and handling equipment. Companies must reconcile the desire to maximize vehicle fill with the need to protect products from damage in transit, and to minimize handling costs. A study of vehicle utilization at European level by consultants A.T. Kearney (1997) concluded that "There are 15% extra grocery trucks on European roads as a result of a failure to optimize available height."

2.2.1.1 *Other Environmental good practices in freight transportation*

Regular vehicle maintenance can improved fuel efficiency by up to 1.5 percent (OEE, 2001). In Canada, almost 95 percent of the fleets checks tire pressure regularly, and most have a policy on maximum vehicle speed: the EPA estimates that a combination truck driving 55 miles per hour uses up to 20 percent less fuel than a similar truck driving 65 miles per hour. In addition, when discussing tire technologies, controlled tire pressure is not the only solution: tire rolling resistance accounts for nearly 13% of truck energy use. Recent tests of wide-base tires indicate a potential fuel economy improvement of 2 to 5 percent compared to equivalent dual tires (EPA, 2004). Close to 70 percent of the fleets delivered some form of driver training in fuel efficiency, which could lead to a 16 to 25 percent decrease in GHG emissions (Rafael-Morales & Cervantes-de Gortar, 2002; Nix, 2003); about 24 percent had driver incentive programs. More and more fleets are programming engines to shut off automatically after a set period of idling. Thirty percent of the fleets used add-ons, such as cab heaters, to minimize idling. Also, all fleet are taking advantage of improved engine technology: fuel efficiency can be improved by as much as 10 L/100 km when switching from mechanical engines to the first generation of electronic engines. New generation of electronic engines can improve fuel efficiency by a further 4 L/100 km. Enhanced vehicle specifications and aerodynamics can improve fuel efficiency by up to 10 percent of the fleet average. Cutting drag by 25 percent could raise fuel economy up to 15 percent at highway speed (EPA, 2004). In conclusion, manage the lifecycle performance of delivery fleet can lead to significant fuel efficiency.

2.2.2 Personnel Transportation

With an increase in passenger vehicles of about 40% between 1995 and 2005 in Canada only (United Nation Economic Commission for Europe (UNECE), 2006), a study on GHG emissions cannot be complete without the consideration of the impact of personal transportation, even if considered as scope 3 emissions.

Organizations are becoming aware of the environmental impact of employees commuting to work. Solutions such as telecommuting or web-based conferencing are encouraged in geographically spread companies (CBORD Inc., 2008; Morgan Cole Inc., 2008; Sun Microsystems Inc., 2008; WRI, 2008; Hewlett-Packard Inc., 2008). For example, The AT&T telecommuting program allowed the saving of 5.1 million gallons of gasoline or the equivalent of about 110 000 miles not driven. This translates to about 48 tons of CO_2 emissions avoided annually (Atkyns, Blazek, Roitz, & AT&T, 2002). Other corporate solutions include using "renewable energy certificates," to offset the emissions resulting from official travel and employee's commuting (National Renewable Energy Laboratory (NREL), 2008), carpooling assistance programs (Sustainable Silicon Valley, 2008), compressed work week options or shuttle services (Centres for Disease Control and Prevention, 2000).

A recent study was done in the École Polytechnique de Montreal showing that, in 2005-2006, the daily transportation of students and university staff was the most important source of GHG emissions in the school, surpassing by 39% those linked to building operations such as heating (Comité de Gestion Environnementale de Polytechnique, 2008). In the case of a logistic platform, no comparative analysis seems to have been done on the relative environmental impact of employees commuting to work. The case of the Polytechnic School of Montreal is another one that suggests strongly quantifying such impact.

A detailed measuring tool was developed to estimate GHG emissions from employees commuting. It is based on the Greenhouse Gas Protocol (GHG Protocol) which is a widely used international accounting tool for government and business leaders to understand, quantify and manage greenhouse gas emissions (The GHG Protocol, 2006). Applicable to any organization, this tool is a comprehensive Excel workbook that calculates GHG emissions based on the required information listed in Table 2-6. Another methodology for calculating emissions from employees commuting was created by the EPA, however it does not offer the same exhaustive details, but included one additional factor which is business related travel (EPA, 2009).

When discussing personal transportation, one of the main factors to be environmentally friendly rests on one's will to modify his travelling habits. Change can be influenced by various incentives (monetary or not), by the media, by local culture, or any other external factors. In the UK, Travel behavior change programs are becoming popular and appear to be effective if we look at a pilot project done on 383 households in the early 2000: the overall distance travelled by car decrease by 14% (Rose & Ampt, 2003).

Table 2-6: Data required for the calculation of GHG emissions due to employees commuting (The GHG Protocol, 2006)

GENERAL INFORMATION	INFORMATION ON TRANSPORT MODE
a. Distance travelled from home to work b. For full time / part time employees: i. Average number of days worked from home annually ii. Average number of days per year spent on business travel iii. Average of days taken on extended leave other than vacation iv. Average of days a week worked (Part-time only) v. Average of weeks a year worked (Part-time only)	Car/bike/walk/train/metro/bus c. Commuting by car: i. Number of days per week driven on the way to work ii. Number of miles driven on the way to work iii. Average # of people in the car iv. Fuel economy of the car (mpg) v. Fuel source of the car d. Commuting by bike/walking /metro/train/bus i. Number of days per week using each transport mode ii. Number of miles travelled using each transport mode
OTHER INFORMATION e. Does average commuting pattern change significantly depending on the time of year? f. If travel habits to go home are not the same as to go to work, the same information as in c), d) and e) should be asked.	

Between 1996 and 2006, the proportion of the Canadian active population driving to work remained relatively stable: ~66% in the Montreal region, compared to ~73% for the province of Quebec and ~73% nationally (**Erreur ! Source du renvoi introuvable.**).

Nationally, from 2001 and 2006, the number of people getting to work as a passenger in a car increased by 22%. New carpool lanes in several urban areas across Canada and the increase in the price of gas, along with more environmental awareness, are among the factors that account for this increase in the number of passengers.

Also, in 2006, Montréal was one of the three census metropolitan areas (CMA) with the highest public transit use, with 21.4% of its active population, along with Toronto (22.2%), and Ottawa - Gatineau (19.4%). The extent to which public transit is used in the different CMAs depends on a number of factors, including: population density, concentration of jobs in sectors that are well serviced by public transit, the cost of using cars compared to public transit, the availability of parking close to work, the quality of service, etc. In general, the largest CMAs have more features that make public transit more appealing to many workers. Among other things, they are more likely to have a well-established public transit system.

Table 2-7: Employed labor force by mode of transportation to work in percentage

	Montreal			Quebec			Canada		
	1996	**2001**	**2006**	**1996**	**2001**	**2006**	**1996**	**2001**	**2006**
Car, truck or van, as driver	66.7	65.8	65.4	73.1	72.9	72.7	73.3	73.8	72.3
Car, truck or van, as passenger	5.5	4.8	5	6	5.3	5.5	7.4	6.9	7.7
Public transit	20.2	21.6	21.4	11.8	12.8	12.8	10.1	10.5	11.0
Walked to work	5.9	5.9	5.7	7.4	6.9	6.6	7	6.6	6.4
Bicycle	1	1.3	1.6	1	1.2	1.4	1.1	1.2	1.3
Other method*	0.6	0.7	0.8	0.7	0.8	0.9	1	1.1	1.2

* Corresponds to the remaining modes of transportation, such as motorcycle, taxi or 'other modes', such as inline skating, snowmobile, etc.

Certain demographical groups are more inclined to use this type of sustainable transportation systems: young people (for example, in Montreal CMA, among workers aged 25 to 34, the use of sustainable transportation, increased from 29.5% in 2001 to 32.9% in 2006), recent immigrants, low income workers who have no car, or people living in the central neighborhoods of large cities. Some of them 'choose' public transit because they have no alternative. Other groups, however, are traditionally less inclined to use public transit or to walk or cycle to work. These are workers who live in the suburbs, workers in the manufacturing sector and workers aged 35 and over.

In terms of distance, the greater it is between the place of residence and the place of work, the less likely workers are to use a sustainable mode of transportation to get there. In 2006, 56.5% of workers in CMAs living within one kilometer of their place of work used a sustainable mode of transportation to commute. Among workers in CMAs who had to travel 15 kilometers or more, the proportion dropped to 15.8%. This reality is understandable for several reasons. First, for most workers, there is a distance beyond which cycling or walking become impossible. Second, the longer the trip between home and work is, the greater the chance of having to transfer between public transit routes, making travel time longer and hence public transit less attractive.

Finally, workers who travel the longest distances to get to work also tend to live in the peripheral sectors of CMAs, where cars are the preferred mode of transportation.

Nevertheless, when looking at the geographical distribution of the population, we can see that about 60% of Canadians live less than 10km from their workplace (Table 2-8).

In general, workers tend to live close to where they work, often in the same municipality. However, the average amount of time it took to get to and from work increased by 16.2% in Toronto between 1992 and 2005, and by 22.6% in Montreal. The gap between the slow increase in distance and the fast increase in commute times may be due to greater road congestion which leaves many commuters having to spend more time than before covering practically the same distance (Statistics Canada, 2008 a)).

Few government-supported programs to improve accessibility to the workplace are targeting employers; they include a series of measures put in place by the employer including improvement of public transit, promotion of carpooling and active modes of transport (cycling, walking), as well as the establishment of partnerships with local

Commuter Management Centers (CMC) (Environment Canada, 2008 a)). Similar initiatives are also government-supported in the US (EPA, 2007).

In conclusion, location of a work site seems to be a crucial factor in determining the travelling habit of an employee, but is clearly not the only one: Even in cities like Montreal, where transit systems are well established, the use of car continues to be predominant in the city and, also across the country for the past decade.

Table 2-8: Commuting distance between work and home (Statistics Canada, 2008 b))

	2001						2006					
	Median commuting distance	Less than 5 km	5 to 9.9 km	10 to 14.9 km	15 to 24.9 km	25 km or more	Median commuting distance	Less than 5 km	5 to 9.9 km	10 to 14.9 km	15 to 24.9 km	25 km or more
	Km	**Percentage**					**Km**	**Percentage**				
Canada	7.2	36.3	22.7	13.3	13.7	14.0	7.6	37.7	23.1	13.3	13.2	12.8
Québec	7.3	35.4	23.4	14.5	14.5	12.1	7.8	37.4	23.8	14.2	13.8	10.7
Montreal	8	34.0	24.9	16.2	16.9	8.1	8.1	33.6	24.7	16.1	16.9	8.7

Another option to decrease commuting-related emissions could be in the choice of the car an employee uses. Various governmental programs have been launched to educate and increase awareness on the different environmentally friendly options available (Governement of Canada, 2008 a)) . In Canada, few of them are of interest for the driving consumer such as:

- The ecoENERGY for Personal Vehicles, providing Canadian motorists with helpful tips on buying, driving and maintaining their vehicles to reduce fuel consumption and greenhouse gas emissions.
- The ecoAUTO Rebate Program, encouraging Canadians to buy fuel-efficient vehicles by offering rebates towards the purchase of more fuel-efficient.

As previously mentioned, other incentives are also included in the sustainable development strategy of the Canadian government: elimination of vehicle sales tax, free parking and permission to drive on high occupancy vehicle (HOV) lanes with one passenger if in a hybrid vehicle (Transport Canada, 2004).

Reducing fuel consumption is synonym to saving money, which is a motivational factor to get informed on the latest car innovations and good driving habits. The Office of Energy Efficiency (OEE) at National Resources Canada (NRC) develops annually a Fuel Consumption Guide since the year 2000 (OEE, 2008). The guide is a tool of comparison of fuel consumption for over 1,000 vehicles. Among all model presented, the most efficient one in CO_2 emissions in 2008 is the Toyota Prius, 1.5 L, 4 cylinder hybrid, with continuously variable transmission: its annual fuel use ranges to about 820 L and its yearly CO_2 emissions add up to 1968 kg.

However, what is the potential market for hybrid cars? A survey done within the Montreal area revealed a large potential demand for cleaner fuel-efficient and electric vehicles if these can compete with conventional vehicles in price and performance. More than a third of respondents stated that they were willing to pay CAN$1,000 more for a car with lower emissions (Ewing & Sarigöllü, 1998). A similar survey in the metropolitan area of Hamilton showed that individuals consider costs and performance characteristics of vehicles as important when choosing their next vehicle. Also, they are attracted to ''tax-free purchase'' incentives and vehicles with significantly reduced emission levels. On the other hand, incentives such as ''free-parking'' and ''permission to drive on HOV lanes with one person in the car'' seem to not affect preferences towards cleaner vehicles (Dimitris & Kanaroglou, 2007).

Hybrid vehicles entered the market fairly recently, and are considered to be suited to play a role, in the near future, in energy policy schemes aiming at reducing CO_2 emissions from individual road transport (De Haan, Peters, & Scholz, 2007). Some of the barriers faced by hybrids to gain market are their high first cost, on-board limited fuel storage, lack of re-fuelling infrastructure, safety issues and improvements in the competition (better, cleaner gasoline vehicles). However, the new generation of hybrid cars such as the Toyota Prius and Ford Escape hybrid are overcoming these barriers and allow a 30% to 50% reduction in greenhouse gas emissions as well as a 90% reduction in tailpipe emissions (Romm, 2006).

Another comparative study was conducted on two Hybrid Electric Vehicles (HEV): the 2005 Toyota Prius II (full Hybrid) and the 2003 Honda Civic IMA (mild hybrid) (Fontarasa, Pistikopoulosa, & Samaras, 2008). Results were that the fuel economy benefit of both peaked under urban driving conditions where reductions of 60% and 40% were observed, respectively under the used driving course. Over higher speeds the difference in fuel economy was lower, reaching that of conventional diesel at 95 km h^{-1}. Also, ambient temperature affects the battery of Prius II with colder weather, reducing its capacity and hence reducing fuel economy, which might suggest that Canadian winters might not be the best environment for a hybrid car.

When looking at the global environmental impact of a car, fuel consumption/economy may be considered only part of the equation; however it remains the most visible area to the public. A study was undergone to determine the *total* energy consumption for the automobile industry (CNW Marketing Research Inc, 2007) – literally from dust to dust. The goal was to identify every conceivable energy required action necessary to conceive, produce, drive, and dispose of a vehicle. With a society that is becoming increasingly interested in fuel economy and global warming, consumers are beginning to make choices about the vehicles they drive based on fuel economy and to a lesser degree emissions. This research was done to broaden the knowledge of the general public when making such choice: it aims to provide information on vehicle lifetime energy usage and the cost to society over the full lifetime of a car or truck, showing that a true "green choice" of car does not limit itself to fuel consumption of the car during ownership time. Some results of this study suggest that hybrid cars use less gasoline and produced fewer tailpipe emissions, but costs society significantly more in overall energy costs than conventional Internal Combustion Engine (ICE) vehicles: the life expectancy of Hybrids as a group is low (12.1 years) compared to Premium SUVs (22.2 years).

This study offers a different perspective than most studies done on hybrid cars; however it is not proven scientifically. It serves as a more philosophical point of view, and will only be considered as such in the context of this study.

2.3 Commercial buildings

Canada accounts for over 440,000 buildings in the Commercial and Institutional Sector (CIS) (OEE, 2007 b)), responsible for about 14% of the total energy use in the country (Figure 2-3). Between 1990 and 2003, energy in the CIS increased by 36% (Figure 2-8). This is explained by the increased commercial activity and the additional use and penetration of auxiliary equipment (e.g. computers). The energy efficiency of commercial/institutional buildings, heating and cooling equipment, lighting technology, electric motors and control systems improved. Without these advances, energy use in the sector would have increased by 37 percent (OEE, 2006).

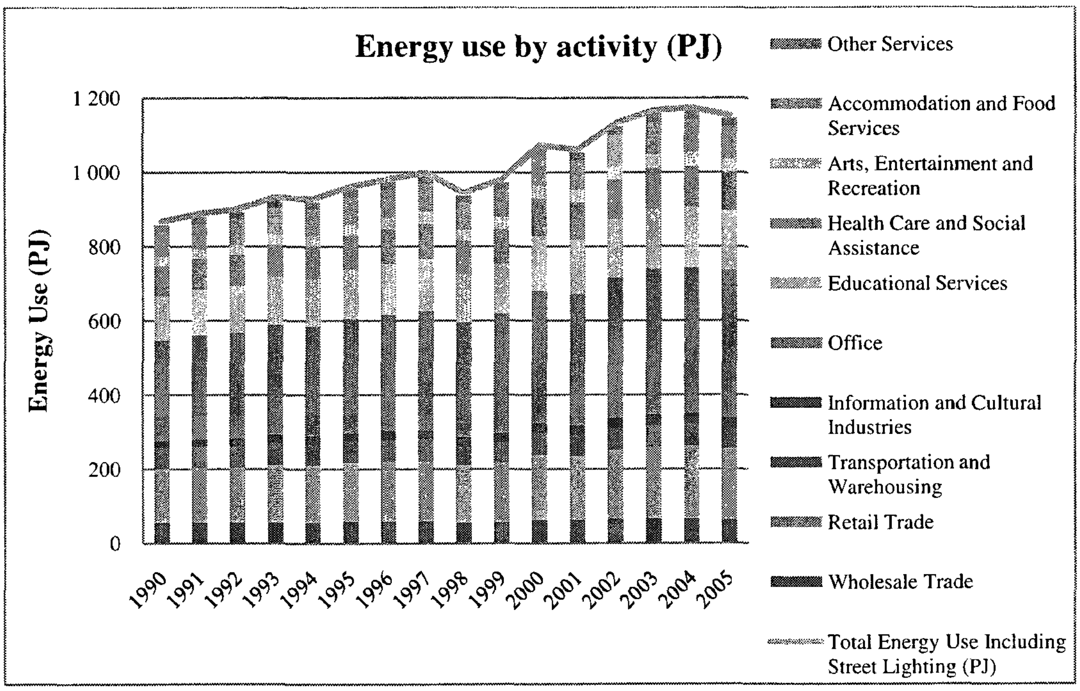


Figure 2-8: Energy use in the commercial/institutional sector between 1990 and 2005 (OEE, 2007 a))

More than half of the total energy use in the CIS is destined for space heating. Auxiliary equipments include stand-alone equipment powered directly from an electrical outlet such as computers, photocopiers, refrigerators and desktop lamps. It also includes equipment that can be powered by natural gas, propane or other fuels, such as clothes dryers and cooking appliances. They represent 14% of the total energy use in the CIS. Auxiliary motors, referring to devices used to transform electric power into mechanical energy in order to provide a service, such as pumps, ventilators, compressors and conveyors, account for 8%. Lighting and space cooling accounts for 9% each of total energy use (Figure 2 - 10). Emissions are almost in the same proportions (Figure 2-9).

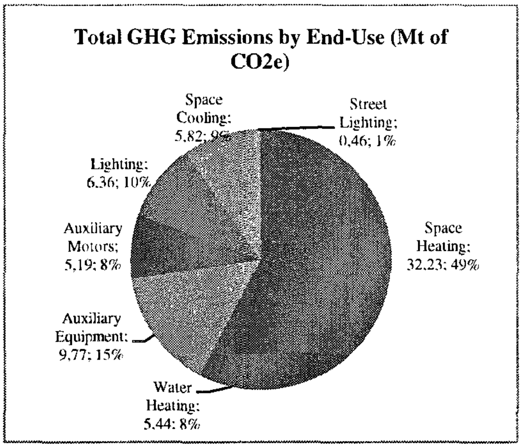


Figure 2-9: Total GHG Emissions in the Commercial and Institutional sector by End-Use (Mt of CO_{2eq}) in 2005 (OEE, 2007 c))

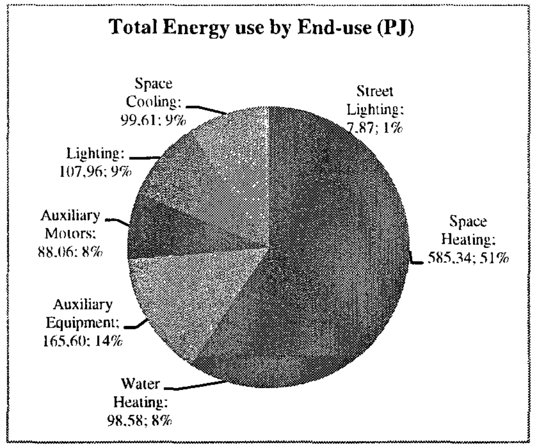


Figure 2-10: Total Energy use in the Commercial and Institutional sector by End-use in 2005 (PJ) (OEE, 2007 c))

GHG emissions from the CIS increased by 45 percent between 1990 and 200 (Figure 2-8). Part of the increase was due to a shift toward heavy fuel oil in the fuel mix and the use of more GHG-intensive fuels to generate electricity (OEE, 2006): the use of Coal and Propane, Heavy and Light Fuel Oil and Kerosene combined increased by 86% (Table 2-9)

Table 2-9: Energy Use by Energy Source (PJ) in 1990 and 2003 (OEE, 2007 a))

Energy Source	1990	2003	Variation
Electricity	390	474	21.6%
Natural Gas	387	525	35.6%
Light Fuel Oil and Kerosene **(A)**	62	80	29.3%
Heavy Fuel Oil **(B)**	11	54	371.2%
Steam	0	0	66.8%
Coal and Propane **(C)**	16	33	102.5%
A+B+C	90	167	86.0%

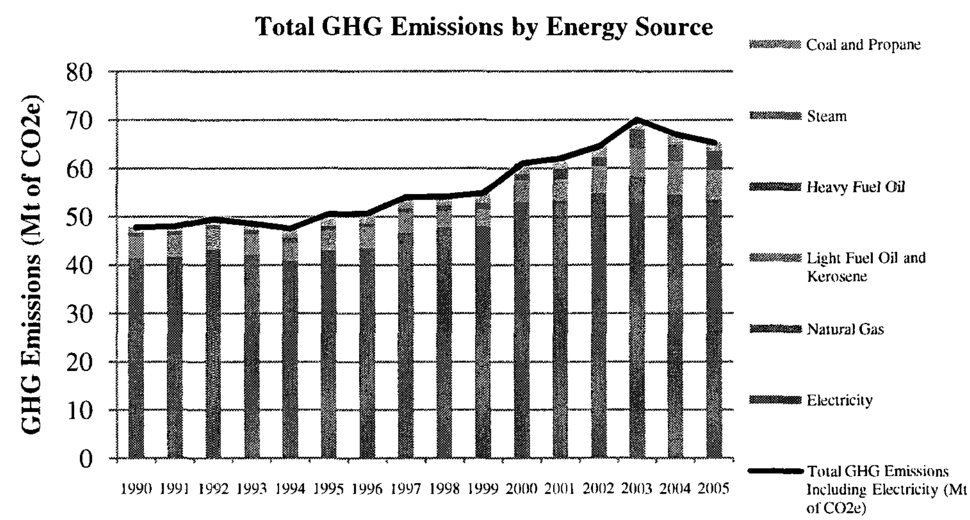


Figure 2-11: Total GHG Emissions by energy Source (Mt of CO_{2eq}) from 1990 to 2005 (OEE, 2007 c))

The following section will debrief on a more micro level: The CIS accounts for a transportation and warehousing activity, and it is the one that includes the various operations of a logistic platform. We will see how energy and GHG emissions vary in this particular sector of the CIS.

2.3.1 Canadian overview of the Transportation and Warehouse activity

The Transportation and Warehousing Activity (TWA) accounts for 5% of the energy use of the CIS (Figure 2-12) as well as 5% of the total GHG emissions of the sector (Figure 2-13). It is important to note that the *Office* activity includes activities related to finance and insurance; real estate and rental and leasing; professional; scientific and technical services; and public administration. It is fair to assume that any office related activity in the context of warehousing is not included in the *Office* activity.

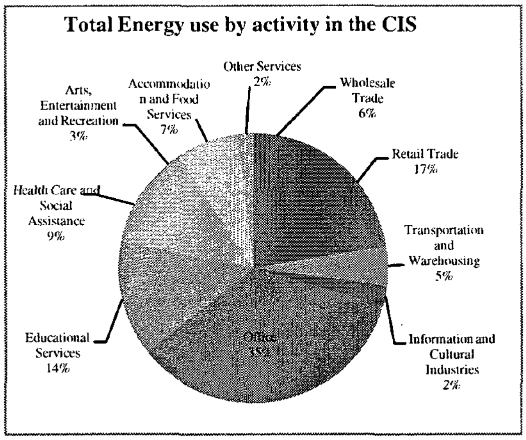


Figure 2-12: Total Energy use by Activity in the Commercial and Institutional Sector in 2005 (OEE, 2007 c))

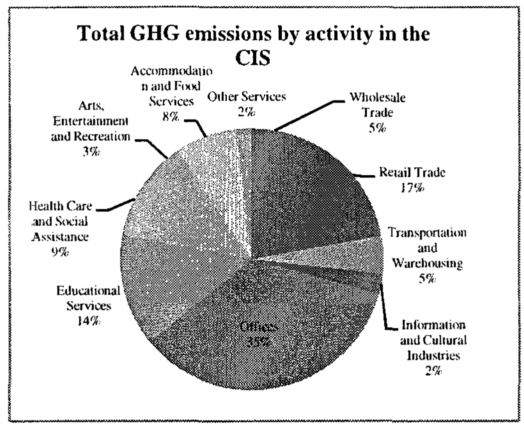


Figure 2-13: Total GHG Emissions by Activity in the Commercial and Institutional Sector in 2005 (OEE, 2007 c))

When looking within the TWA, 63% of the energy used is for space heating, 12% is for lighting, 10% for auxiliary motors, 7% for cooling space, 4% for water heating and 4% for auxiliary equipments (Figure 2-15). GHG emissions for end-use are in the same proportional range (Figure 2-14). One can estimate a similar distribution of energy within its facility, however energy distribution in warehouse can vary dramatically on a smaller scale depending on the type of product put in stock (ex: frozen foods require cooling whereas clothing do not).

When looking at energy sources used in the TWA, Electricity and Natural Gas are the two most widely used form of energy. However, it is evident that these energy sources don't have the same emission potential in terms of proportions: for example, 50% of the energy used is Natural Gas, but this source only accounts for 44% of GHG emissions in the TWA (Figure 2-16).

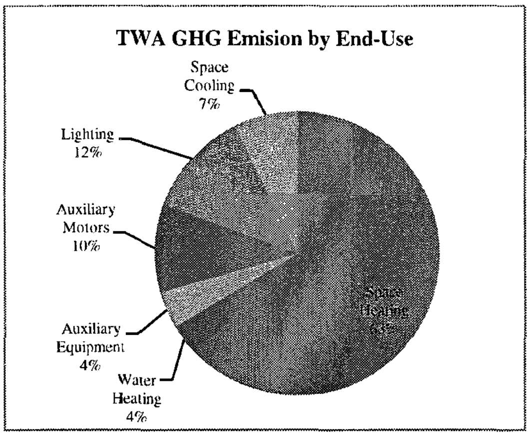


Figure 2-14: GHG Emissions by End-Use in the Transportation and Warehousing activity in 2005 (OEE, 2007 c))

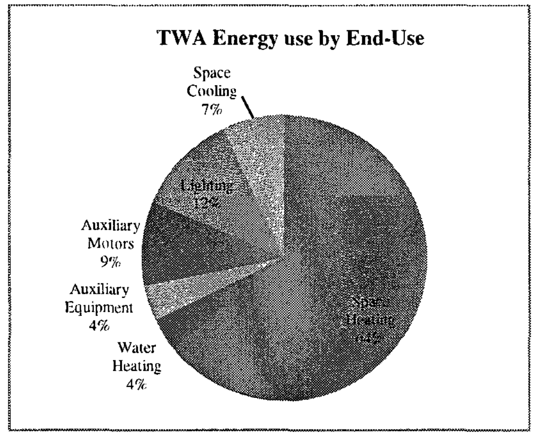


Figure 2-15: Energy use by End-Use in the Transportation and Warehousing activity in 2005 (OEE, 2007 c))

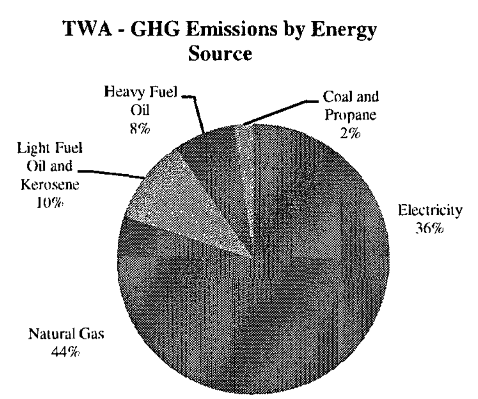


Figure 2-16: GHG Emissions by Energy Source in the Transportation and Warehousing activity in 2005 (OEE, 2007 c))

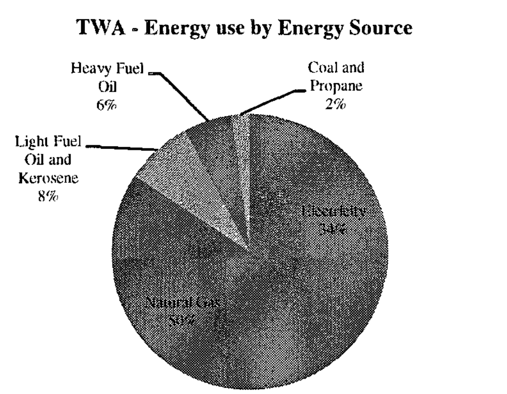


Figure 2-17: Energy use by Energy Source in the Transportation and Warehousing activity in 2005 (OEE, 2007 c))

It is can also be noted that when comparing energy use and GHG emissions by End-Use, the proportions do not vary much: the reason is that each End-Use uses mainly the same Energy Source, hence keeping the relative proportions almost identical. For example, lighting and auxiliary motors are powered solely by electricity. Figure 2-18 shows the energy use of the other End-Use. Other than space and water heating which are powered more than 65% by Natural Gas, Auxiliary equipments and space cooling is powered at more than 90% by Electricity.

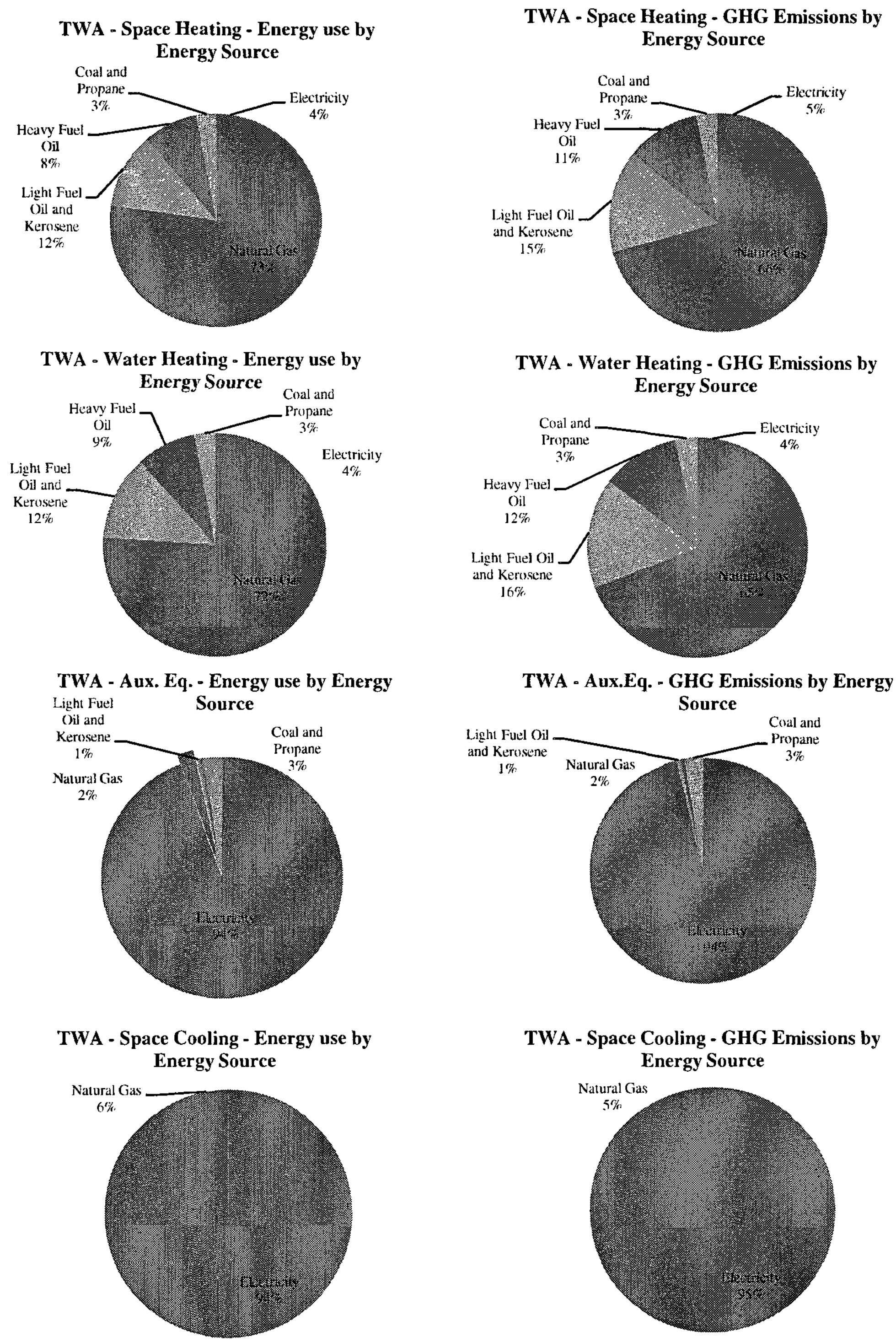


Figure 2-18: Energy use and GHG Emissions by Energy source for each End-Use of the Transportation and Warehousing Activity in 2005 (OEE, 2007 c))

2.3.2 Sustainable buildings

A recent study showed that there is no significant difference in average costs for green buildings as compared to non-green buildings (Matthiessen & Morris, 2007).

There are many rating systems when it comes to sustainable constructions. The most widely used measure, at least in the United States, is the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system. This system has four levels - Certified, Silver, Gold, and Platinum - that can be achieved by earning a series of points from five categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, and Indoor Environmental Quality. Points can also be earned for Innovation and Design Process (Morris, 2007). New constructions of distribution centers are incorporate sustainable design including better roof insulation, variable air-volume ventilation systems that operate based on space temperature demands (Yoders, 2006), use of solar panels for water heating, roof drainage systems that enable harvesting rainwater to be reused in toilets, landscape irrigation or for washing equipments, reduction of artificial lighting with installation of skylights and clerestory window (DiBenedetto, 2008; Witt, 2007), or the use of more efficient lighting such as T5 or T8 can dramatically reduce electricity use (Aker, 2008) . Also, companies are taking into consideration how their building will fit in their operation, for instance, whether it's a stand-alone facility or part of a regional or national network. Companies now consider site locations that employees can reach by public transportation and carpooling as part of their green strategy.

The treatment of waste is also an essential part of how sustainable a commercial facility is: recycling and re-using waste programs are becoming an essential strategic business opportunity as well. The reduction of CO_2 emissions is synonym to greener operations, but it is representative of more efficient operation, impacting the bottom line of a company's budgets and profits (Pendrous, 2008; Witt, 2007).

2.4 GHGs, Emission factors and existing calculation methods

The purpose of the section is to find the common factor that will allow the comparison of emissions from various sources, for example, transportation emissions vs. building emissions. The energy source for both are not the same, hence we need to find an equivalent factor that will allow rationalization and therefore benchmarking.

Even though they are part of the natural balancing system of the planet, GHGs, such as water vapor (H_2O) and carbon dioxide (CO_2), are present in the atmosphere due to both natural processes and human activities. However, others are almost entirely present due to anthropogenic (man-made) sources such as chlorofluorocarbons (CFC) or hydrofluorocarbons (HFC) (Environment Canada, 2003).

Greenhouse gases are not equal. In fact, each GHG has a unique average atmospheric lifetime and heat-trapping potential. Greenhouse gas emissions are often calculated in terms of how much CO_2 would be required to produce a similar warming effect. This is called the carbon dioxide equivalent (**CO_{2eq}**) value and is calculated by multiplying the amount of the gas by an associated global warming potential (GWP). For example, the GWP for methane (CH_4) is 21, which means that each ton of CH_4 emitted is considered to have a cumulative warming effect over the next 100 years equivalent to emitting 21 ton of CO_2. The scientific community has established a GWP for each of the GHGs subject to reporting under the Greenhouse Gas Emissions Reporting Program. They can be viewed in Table 2-10.

The 2006 IPCC (Intergovernmental Panel on Climate Change) Guidelines for National Greenhouse Gas Inventories, General Guidance and Reporting, provides internationally agreed methodologies intended for use by countries to estimate greenhouse gas inventories to report to the UNFCCC.

Table 2-10: Global Warming Potential of GHGs (Environment Canada, 2005)

Greenhouse Gas	Formula	Global Warming Potential
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Sulphur hexafluoride	SF_6	23,900
Hydrofluorocarbons (HFCs)		
HFC-134a	$C_2H_2F_4(CH_2FCF_3)$	1,300
Perfluorocarbons (PFCs)		
Perfluoromethane	CF_4	6,500
Perfluoroethane	C_2F_6	9,200

Various calculation methodologies and tools have been developed. The IPCC provides calculation methods for emissions based on *Tiers*, which represent a level of methodological complexity. Usually three tiers are provided. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 most demanding in terms of complexity and data requirements. Tiers 2 and 3 are sometimes referred to as *higher tier* methods and are generally considered to be more accurate: In reality emission factors vary depending on fuel type used, combustion technology, operating conditions, control technology, quality of maintenance, and age of the equipment used to burn the fuel (IPCC, 2006).

The EPA developed guidance documents that explain various methods of calculations, based on the guidelines provided by the IPCC (EPA, 2008). In the *Optional Emissions from Commuting, Business travel and Product transport* guidance report, the EPA elaborate on the IPCC's *Tier 1* similar method for calculating emissions for transportation of people and products. The difference between both methods relies on the information required for the calculation and the level of complexity of the method. Worth mentioning also are the tool sets that were developed by the GHG protocol to calculate emissions from various sources (The GHG Protocol, 2009).

We will only present the methods that will be used in the context of this research.

2.4.1 GHG emissions from stationary combustion

Both the EPA and IPCC (Tier 1) provide with a similar methods of calculation when it comes to stationary combustion. Both methods require the following for each source category and fuel:

- Data on the amount of fuel combusted in the source category
- A default emission factor

The following equation is used (***Equation 1***):

$$Emissions_{GHG,Fuel} = Fuel\ Consumption_{Fuel} * Emission\ Factor\ _{GHG,Fuel}$$

Where:

- Emissions $_{GHG,\ fuel}$ = emissions of a given GHG by type of fuel (kg GHG)
- Fuel Consumption $_{fuel}$ = amount of fuel combusted or used (TJ) or (m^3) or (MWh)
- Emission Factor $_{GHG,\ fuel}$ = default emission factor of a given GHG by type of fuel (kg gas/TJ) or (kg gas/ m^3) or (kg gas/MWh). For CO_2, it includes the carbon oxidation factor, assumed to be 1.

To calculate the total emissions by gas from the source category, the emissions as calculated in Equation 1 are summed over all fuels and we obtain:

<u>Total emissions for stationary combustion</u> ***(Equation 2):***

$$Emissions_{GHG,fuels} = \sum Emissions_{GHG,Fuel}$$

It is to be noted that emissions from electricity consumption are generally not reported by countries, as they are considered indirect emissions (Government of Canada, 2008 b)).

2.4.2 GHG emissions from mobile combustion

When it comes to mobile combustion, the IPCC offers a method of calculation that is based on the amount of fuel sold in TJ. However, fuel sold is not information that is inherently easy to obtain. The EPA as well as the GHG protocol provides calculation methods that are based on distance travelled or weight transported for each type of transportation. The main difference is that the EPA offers a method that includes CO_2, CH_4 and N_2O emissions whereas the GHG Protocol only takes into consideration CO_2 emissions in the toolset offered (EPA, 2009).

GHG FROM PERSONAL TRANSPORTATION

Employee commuting by car (***Equation 3)***

$E = VMT * (EF_{CO2} + EF_{CH4} * 21 + EF_{N2O} * 310)$

Where:

- E = Total CO_{2eq} Emissions (in kg)
- VMT = Vehicle Miles Traveled
- EF_{CO2} =CO_2 Emission Factor (kg/vehicle-mile)
- EF_{CH4} =CH_4 Emission Factor (kg/vehicle-mile)
- EF_{N2O} =N_2O Emission Factor (kg/vehicle-mile)
- 21 = Conversion Factor to rationalize global warming potential
- 310 = Conversion Factor to rationalize global warming potential

Employee commuting by public transportation (***Equation 4)***

$E = PMT * (EF_{CO2} + EF_{CH4} * 21 + EF_{N2O} * 310)$

- E = Total CO_{2eq} Emissions (in kg)

- PMT = Passenger-Miles Traveled
- EF_{CO2} =CO_2 Emission Factor (kg/passenger-mile)
- EF_{CH4} =CH_4 Emission Factor (kg/passenger-mile)
- EF_{N2O} =N_2O Emission Factor (kg/passenger-mile)
- 21 = Conversion Factor to rationalize global warming potential
- 310 = Conversion Factor to rationalize global warming potential

GHG FROM FREIGHT TRANSPORTATION

The GHG emissions from on-road vehicle product transport include those from gasoline or diesel, and to a lesser extent, other fuels such as compressed natural gas (CNG). The EPA provides two protocols as guidance for estimating CO_2, CH_4, and N_2O emissions from on-road vehicle product transport: the first one, less complex, is based on emission factors for passenger vehicles, light-duty trucks (i.e., light-duty trucks and other 2-axle, 4-tire vehicles), and medium and heavy-duty trucks (i.e., other trucks, single-unit 2-axle, 6-tire or more trucks, and combination trucks). This method of calculation takes into consideration vehicle-mile travelled or tons per mile travelled, in the case of medium and heavy trucks and can be used when fuel usage or vehicle type information is not available.

The second, more complex, is explained in the Climate Leaders Guidance for *Direct Emissions from Mobile Combustion Sources* (EPA, 2008): It is similar to Tier 2 or 3 of the IPCC and will not be discussed in this paper.

Emissions from freight transportation based on weight (***Equation 5)***

$$E = TMT * (EF_{CO2} + EF_{CH4} * 21 + EF_{N2O} * 310)$$

- E = Total CO_{2eq} Emissions (in kg)
- TMT = Ton per Miles Traveled

- EF_{CO2} = CO_2 Emission Factor (kg/ton-mile)
- EF_{CH4} = CH_4 Emission Factor (kg/ton-mile)
- EF_{N2O} = N_2O Emission Factor (kg/ton-mile)
- 21 = Conversion Factor to rationalize global warming potential
- 310 = Conversion Factor to rationalize global warming potential

This method is well-suited for calculating emissions of transport by rail or sea since emission factors are only given in terms of kg of CO_{2eq} / ton-mile. However, for road transport, this method does not take into account the volume of the products that are being shipped. For low density products with high volume, the estimation might be undervalued since only weight is considered. Hence, this method does not allow the study of the effect of better load consolidation or improved truck fill rate.

The French agency of the environment and the energy control, the ADEME, (*Agence de l'Environnement et de la Maîtrise de l'Energie*) developed a method called *Bilan Carbone* that allows institutions to calculate their *total* carbon emissions. For transportation, their methodology is more thorough and complex than the EPA's Climate Leaders' and includes factors such as the fill rate, emissions factors of both empty and loaded vehicles, emissions that were generated by the fabrication and amortization of the vehicle (ADEME, 2007).

The ADEME presents also two types of calculations for road transportation: one based on vehicle-km and one based on ton-km.

For the vehicle-km calculation, the ADEME takes into consideration the average consumption per vehicle-km per type of vehicle, easily obtained in the context of a company managing its own transport fleet. This information can also be estimated by using national averages.

The reasoning behind the ADEME method is that in practice, road vehicle are only loaded on a part of their trip, with a variable load, and are empty on the rest of the trip. The method considers that the consumption of a vehicle – hence the GHG emissions -

varies linearly with the load transported. In fact, to evaluate GHG emissions, the factors to determine are:

1. Emissions per km of vehicle running empty (e_{empty})
2. Emissions per km of vehicle fully loaded ($e_{fully\ loaded}$)
3. The weight of the maximum load that can be carried by the vehicle (L)
4. The fraction of distance ran empty by the vehicle ($T_{d.empty}$)
5. The average fill rate of the vehicle on the loaded part of the distance travelled ($T_{fill\ rate}$)

The first three factors are characteristics of the vehicle used, whereas the last two are linked to the utilization of that vehicle. Therefore, one can conclude that there are only two variables to determine. Emissions per vehicle-km (e_{total}) are given by:

$$e_{total} = e_{empty} * T_{d.empty} + e_{partially\ loaded} * (1 - T_{d.empty})$$

with :

$e_{partially\ loaded}$ = emissions per vehicle-km of the vehicle partially loaded.

With the hypothesis of linear augmentation of the consumption with the load L, we can write that:

$$e_{partially\ loaded} = e_{empty} + (e_{fully\ loaded} - e_{empty} * T_{fill\ rate})$$

Hence:

$$e_{total} = e_{empty} * T_{d.empty} + [e_{empty} + (e_{fully\ loaded} - e_{empty}) * T_{fill\ rate}] * (1 - T_{d.empty})$$

Or

$$\boldsymbol{e_{total} = e_{empty} + (e_{fully\ loaded} - e_{empty}) * T_{fill\ rate} * (1 - T_{d.empty})} \quad \textbf{\textit{(Equation 6)}}$$

In conclusion, if $e_{fully\ loaded}$ and e_{empty} are known, we only need to determine $T_{fill\ rate}$ and $T_{d.empty}$.

$e_{fully\ loaded}$ and e_{empty} can be determined using the COPERT III methodology cited by ADEME, that considers:

- No variation in consumption between for light vehicle, no matter what load is carried
- For all vehicle with maximum capacity > 3.5t, there is an overconsumption of 44% when fully loaded compared to when running empty.

Therefore:

$$e_{fully\ loaded} = a * e_{empty}$$

Where a is 1 for light vehicle and 1.44 for vehicle with maximum capacity > 3.5t

The ADEME add to Equation 6 the emissions related to the fabrication of the vehicle or a factor e_{fab} to finally obtain ***Equation 7***:

$$e_{total} = e_{fab} + e_{empty} + \left(e_{fully\ loaded} - e_{empty}\right) * T_{fill\ rate} * \left(1 - T_{d.empty}\right)$$

In the case of a company - like the one understudy - that subcontracts its entire transport of goods, the type of information that is available is usually limited to the weight of the products shipped out and also the distance travelled by the products in order to reach the customer hence, ton-km.

The ADEME considers the typology of transport of goods. In Europe, the road transport field is standardized in the sense that it is possible to link the type of vehicle used to the unitary weight of a shipment. Also, the average fill rate can also be averaged out depending on the type of vehicle used and on the field expertise of a transporter.

In order to convert tons-km to vehicles-km, the ADEME considers the following:

- In the case of dedicated transport, i.e. transport of only one company's goods:

$$Vehicles - km = (tons.km) \div (Average\ load\ of\ the\ shipment)$$

For example, if 1ton-km is transported by a vehicle of average load of 4 tons, which would mean the vehicle travelled 250km.

- In the case of non-dedicated transport, i.e. transport of multiple company's goods:

$$\text{Vehicles} - \text{km} = [(\text{tons.km}) \div (\text{Average load of shipment})] * (\text{\% of the load owned by the company})$$

Also, $\text{Average load of a shipment} = \text{maximum load} * T_{fill\ rate}$

Hence, to convert tons-km to vehicles-km, we have:

(i) Kg CO_{2eq} per ton.km = Kg CO_{2eq} per vehicle.km ÷ (maximum load x average fill rate on the entire travelled distance)

With:

Average fill rate on the entire travelled distance = (Average load transported x distance travelled with load) ÷ (Maximum load x total distance)

Hence:

Average fill rate on the entire travelled distance =

Average load transported * (distance travelled with load ÷ total distance) ÷ Maximum load

And with:

(ii) $\text{Average fill rate on the entire travelled distance} = T_{fill\ rate} * \left(1 - T_{d.empty}\right)$

Combining (i) and (ii) we get:

$$\text{Kg } CO_{2eq} \text{per ton.km} = e_{total} \div [\text{L} * T_{fill\ rate} * \left(1 - T_{d.empty}\right)]$$

Therefore:

$$e_{total(ton\ based)} = [e_{total} \div \left(1 - T_{d.empty}\right)] \div [\text{L} * T_{fill\ rate}]$$

We finally obtain ***Equation 8***:

$$e_{total(ton\ based)} = [e_{total} \div (1 - T_{d.empty})] \div \mathrm{L}_{average}$$

where $\mathrm{L}_{average}$ is the average load transported.

Hence, this shows the relationship between emissions by ton-km and by vehicle-km. However, in order to implement this approach, one needs to know the average fill rate of the vehicle. If this information is not available, the fill rate will have to be estimated.

The ADEME states some uncertainties in the methods to obtain ***Equation 7*** and ***8***:

a. National averages are used to obtain consumptions and emissions per type of vehicle
b. Some national averages do not distinguish between vehicle owned fleet and third party transportation. In-house transportation is usually less efficient.
c. With the exception of truck load transport, it is impossible to know at each shipment the exact composition of the loaded vehicle, that carries other company's goods

2.4.3 Emission factors

All the methods shown earlier use emission factors depending on various fuels. Extensive database for emission factors can be found on the IPCC website or also on the EPA website. The databases include emission factors related to a specific fuel used, a technology used, a equipment used or even a condition under which the equipment is used (for example, if engine is running hot or cold) (IPCC, 2006).One can also look for them in the National Inventory reports, located in governmental website (Environment Canada, 2008 b)).

Since information such as condition of operation of an engine, type of engine or even type of internal combustion is not available, it is logical to use average emission factors, that can be found on government web sites, in order to conduct our calculations (Environment Canada, 2008 b); EPA, 2008). We listed the pertinent ones in Table 2-11,

Table 2-12 and Table 2-13.

Table 2-11: Emission factors for stationary combustion (Environment Canada, 2004; 2008 b))

GHG Emissions Factors for Electricity		
$kgCO_{2eq}/kWh$		
Ontario average in 2002	**Quebec average in 2002**	**Nova Scotia average in 2000**
0.258	0.0018	0.759
Emissions Factors for Natural Gas		
CO_2	**CH_4**	**N_2O**
g/m3	**g/m3**	**g/m3**
1891	0.49	0.049

Table 2-12: Emission factors given by the EPA for mobile combustion (EPA, 2009)

	CO_2 Emission Factor (kg /vehicle-mile)	CH_4 Emission Factor (g /vehicle-mile)	N_2O Emission Factor (g /vehicle-mile)	**CO_{2eq} Emission factor (kg/vehicle-mile)**
Vehicle Type				
Passenger Car	0.364	0.031	0.032	0.375
Light-duty Truck	0.519	0.036	0.047	0.534
Medium- and Heavy-duty	1.726	0.021	0.017	1.732
Motorcycle	0.167	0.07	0.007	0.171
	CO_2 Emission Factor (kg/passenger-mile)	CH_4 Emission Factor (g /passenger-mile)	N_2O Emission Factor (g /passenger-mile)	**CO_{2eq} Emission factor (kg/passenger-mile)**
Public Transportation				
Bus travel	0.107	0.0006	0.0005	0.107
Intercity Rail (e.g., Amtrak)	0.185	0.002	0.001	0.185
Commuter Rail	0.172	0.002	0.001	0.172
Transit Rail (e.g., Trams and Subways)	0.163	0.004	0.002	0.164
Airline Travel Distance				
Long Haul (>> 700 miles)	0.185	0.0104	0.0085	0.188
Medium Haul (>> 300 and < 700 miles)	0.229	0.0104	0.0085	0.232
Short Haul (< 300 miles)	0.277	0.0104	0.0085	0.280
Distance Not Known	0.271	0.0104	0.0085	0.274
	CO_2 Emission Factor (kg CO_2/ton-mile)	CH_4 Emission Factor (g CH_4/ton-mile)	N_2O Emission Factor (g N_2O/ton-mile)	**CO_{2eq} Emission factor (kg/ton-mile)**
Freight Transportation				
On-Road truck	0.297	0.0035	0.0027	0.298
Rail	0.0252	0.002	0.0006	0.025
Waterborne Craft	0.048	0.0041	0.0014	0.049
Aircraft	1.527	0.0417	0.0479	1.543

Only road transportation has factors expressed in kg CO_{2eq}/vehicle – mile. Rail and marine transportation are only given in kg CO_{2eq}/ton-mile.

It is to be noted that European emission factors are not equivalent to North American ones. North American ones can be up to three times the value of European factors (ADEME, 2007).

Table 2-13: Emission factors for road vehicle (ADEME, 2007)

	Average	Average	Empty vehicle	Full vehicle	Maximum load
Vehicle type (based on Gross Weight Limit)	Kg CO_{2eq} per vehicle - km	Kg of CO_{2eq} per vehicle - mile	Kg CO_{2eq} per vehicle - km	Kg CO_{2eq} per vehicle - km	(tons)
<1.5t gasoline	0.0711	0.114	0.062	0.062	0.4
<1.5t diesel	0.0654	0.105	0.059	0.059	0.4
1.5 to 2.5t gasoline	0.0812	0.131	0.07	0.07	0.7
1.5 to 2.5t diesel	0.0766	0.123	0.068	0.068	0.7
2.51 to 3.5t gasoline	0.1362	0.219	0.123	0.123	1.2
2.51 to 3.5t diesel	0.0981	0.158	0.088	0.088	1.2
3.5t	0.1114	0.179	0.101	0.101	1.4
3.51 to 5t	0.1624	0.261	0.136	0.196	2.37
5.1 to 6t	0.1322	0.213	0.107	0.154	2.84
6.1 to 10.9t	0.1945	0.313	0.158	0.228	4.69
11 to 19t	0.2613	0.420	0.208	0.3	9.79
19.1 to 21t	0.2995	0.482	0.24	0.346	11.62
21.1 to 32.6t	0.372	0.599	0.302	0.435	16.66
Tractors	0.332	0.534	0.252	0.363	25

It is interesting to see the difference between the emission factors given by the ADEME and the EPA. For medium to heavy-duty vehicle, the EPA proposes a factor of 1.732 kg of CO_{2eq}/vehicle – mile where as the ADEME offers a range of factors between 0.313 and 0.599 kg of CO_{2eq}/vehicle – mile. The difference can be attributed to the way these factors were calculated: the EPA simply estimated their factors by dividing the total amount of CO_{2eq} emission found in the *U.S. Greenhouse Gas Emissions and Sinks: 1990–2005* report by the total number of vehicle-miles found in the 2005 *Highway Statistics*. The ADEME calculated their emission factor using more precise information linked to vehicle consumption for each category as well as average life of a vehicle in km.

CHAPTER 3 : METHODOLOGY

As far as our research allowed, the GHG emissions of the various sectors within a logistic platform were never compared. The lack of such information does not allow management committees to establish clear and informed environmental strategic plans, and hence environmental priorities can be difficult to set. In order to fill this information gap, we propose the following methodology that will allow us to estimate GHG emissions in a logistic platform for all identified sectors:

1. Transportation
    a. Transportation of goods
        i. Inbound
        ii. Outbound
    b. Employees commuting
2. Building operations

For each of this sector, we will define the required data needed as well as identify shortcomings and assumptions to be made in order to carry the calculation.
This methodology will be then applied on the logistic platform under study. For simplification purposes, the company understudy will be referred to as CUS.

3.1 Transportation

3.1.1 Transportation of goods

We have seen in the literature review that a few factors need to be considered to study freight movement in general and evaluate their impact. Three ratios have been identified by McKinnon (2003) and they are:

1. **Total ton-kilometers**, which identifies the weight of goods produced and distributed.
2. **Road ton-kilometers** which identifies the split between the road and other modes of transport
3. **Vehicle-kilometers** which determines the amount of vehicle traffic required to handle a given volume of freight

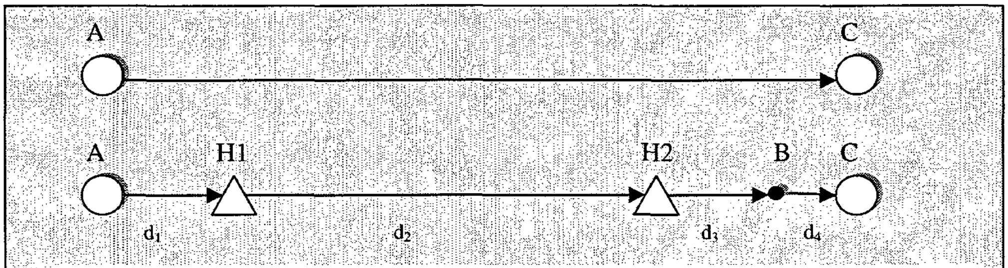
These ratios need to be determined in order to evaluate emissions related to the transportation of goods. We have seen also that emission factors are given under two possible units: kg of GHG / Vehicle-km (or mile) or kg of GHG / ton-km (or mile). In summary, the information required to realize the total GHG emissions' evaluation is:

1. Type of mode used to transport goods
2. Volume and/or weight of the goods transported
3. Distance travelled by the goods
4. Vehicle fill rate
5. Distance travelled by the empty vehicle

However, such data is not always available; as a result it is very difficult to establish a precise calculation method. We need to develop one that will allow us to establish an acceptable estimation of the GHG emissions related to transport. The following section will break down the steps used to establish the calculation.

3.1.1.1 *Outbound transportation*

Outbound transportation includes the movement of all stock delivered from a logistic platform to clients. The typology of transportation of the CUS is represented in Figure 3-1:



A = Origin B = Point of detour C = Client

H1 = First transhipment hub H2 = Second transhipment hub

$d_{1,2,3}$= distances between haul stop d_4 =

Figure 3-1: Typology of outbound transportation

Using the legend stated in Figure 3-1, outbound transport can be generally described as follows:

1) A is the point of origin. In our case, it represents the distribution centre of the CUS from which all products are shipped.
2) C is the final destination, meaning the CUS's client that ordered the products.

Since the CUS subcontracts all its transport activities, it uses different transporters. Transporters are chosen automatically by a rate shopping software that calculates the rate that each transporters offers for a particular shipment. The software takes into consideration the distance to be travelled, the time required to reach the client as well as the volume and weight of the shipment. We will not discuss the method used by the software to choose which transporter will carry the goods.

When a transporter is chosen, the path of the goods is generally done in three phases, as follows:

i. Phase 1: From the CUS's DC to the transshipment hub #1 (**H_1**) of the transporter: The transporter sends a truck to the CUS's DC and loads all the deliveries he will have to carry for the CUS. In order to optimize its transport, a first stop is made by the vehicle to the first hub in order to consolidate the shipments of various other clients in the same region. The distance travelled is $\mathbf{d_1}$. It can happen that the vehicle does a secondary route to pick up other companies' deliveries if possible. It is important to note that each truck leaving the CUS contains multiple orders of multiple clients of the CUS, hence the number of trucks leaving the CUS **does not** equal to the number of deliveries.

ii. Phase 2: At $\mathbf{H_1}$, the transporters will consolidate all deliveries from all their clients (including the CUS') destined to the same region and load different vehicles that will travel towards a specific region. Shipments of the CUS will therefore occupy only a portion of the vehicle space, along with other companies' shipments, and will travel the distance $\mathbf{d_2}$ until the second transshipment hub ($\mathbf{H_2}$). The vehicles used on $\mathbf{d_2}$ are usually maximized in terms of fill rate in order to reduce costs and are either heavy trucks or rail wagons.

iii. Phase 3: Once at $\mathbf{H_2}$, the transporter will unload its vehicle and regroup all deliveries with proximate destinations. Usually, smaller vehicles are loaded and are sent out to finally deliver the CUS's client C, along with other companies' nearby clients. The distance done is $\mathbf{d_3 + d_4}$. $\mathbf{d_4}$ represents the detour that the vehicle has to do in order to reach a CUS's client.

For example, in the case of a shipment from Montreal (Quebec) to Surrey (British Columbia):

- Phase 1: All the CUS's western deliveries will be loaded in the transporter's vehicle to be sent out to $\mathbf{H_1}$, which is in the region of Montreal.
- Phase 2: All the CUS's western deliveries will be combined with other shipments in order to optimize transportation. The dedicated vehicle will travel to $\mathbf{H_2}$, which is for example, in the region of Vancouver.
- Phase 3: Smaller vehicles are loaded with deliveries that have proximate destinations. In this case, all deliveries to be done in the region of Surrey will be loaded in the same vehicle.

It is important to note that in Canada, distance travelled can vary dramatically. The example stated above requires crossing the entire country in order to serve one particular client. However, if the distance to travel is relatively short, one can consider that outbound transportation includes only Phase 1 and 3. For example, all shipments done in the region of Montreal will not include Phase 2 and could also not include Phase 1, if the client is near the CUS's DC.

Another aspect to take into considerations is deliveries to major clients and distributors. Deliveries done to major clients should be analyzed in a different way: These clients usually carry a broad variety of consumer products. They are usually part of chains of stores (Ex: Wal-Mart). The transporter that delivers the CUS's orders usually delivers other products from other suppliers during the same trip. Hence, $\mathbf{d_4}$ can be considered to be equal to 0.

As for deliveries done to major distributors, it is impossible to know the true final destination of a product. Distributors usually act as secondary warehouse that serves a particular niche of clients, such as hair dressers for example. The CUS usually ships to the distributors' warehouse, which in turn serves a niche of clients. How or when this niche of clients is served is transparent to the CUS. In this case, the DC's distributor can be considered as $\mathbf{H_2}$ and $\mathbf{d_3} = \mathbf{d_4} = 0$.

In the case of CUS, the use of rail is not predominant yet. With about 1% of all deliveries done by rail, we will draw the first assumption:

Outbound / A1 All deliveries are done by road

In order to estimate GHG emissions of outbound transportation, two options can be considered: we can either calculate emissions using factors based on ton-km or using factors based on vehicle-km.

When looking at road transportation, as seen in the literature, both factors can be linked according to (ADEME, 2007):

$$\boxed{e_{total\ (ton\ based)} = [e_{total} \div (1-T_{d.empty})] \div L_{average}}$$

The EPA states that (as seen in
Table 2-12):

	CO_2 Emission Factor	CH_4 Emission Factor	N_2O Emission Factor	CO_{2eq}
	(kg CO_2/ton-mile)	**(g CH_4/ton-mile)**	**(g N_2O/ton-mile)**	**(kg/ton-mile)**
On-Road truck	0.297	0.0035	0.0027	0.298
	(kg /vehicle-mile)	**(g /vehicle-mile)**	**(g /vehicle-mile)**	**(kg/vehicle-mile)**
Medium- and Heavy-duty Truck	1.726	0.021	0.017	1.732

If we look at these data, we can roughly estimate that, if we consider $T_{d.empty}$ equal to zero, that $L_{average}$ is around 5.8 tons, which in turn can be translated to:

- 53' trucks having a fill rate of about 40% (Max load weight being 13.2t)[2]
- 24' trucks having a fill rate of about 80% (Max load weight being 7.2t)[3]

The fact that there is no distinction between the different type of trucks could lead to an over or underestimation of GHGs.

For this reason, for road transportation, we will build a calculation model that will use European vehicle-km factors, as they seem more precise, as seen in section 2.4.3.

In order to obtain the vehicle-km ratio and use the correspondent emission factors to calculate the amount of CO_{2eq} in kg, we need the following:

1. The total number of km travelled in phase 1, 2 and 3
2. The number of vehicles that travelled in phase 1, 2 and 3
3. The fill rate of each vehicle in each phase
4. The type of vehicle that travelled in each phase
5. The type of client served (distributor, major client, or small client)

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[2] http://www.fbifreight.com/freight_brokers_truck_specifications.html

[3] Same as 2

With over 8,000 different clients, over 90 million units shipped each year, it is difficult to obtain the listed information above. Therefore, we will draw assumptions that will help us obtain an acceptable, yet simplified calculation method, which will result in workable estimations.

The data that we were able to obtain from the CUS's information system includes:

- The address of each clients
- Specification of daily shipment, sorted by clients. They include:
  - The weight and volume of the shipment
  - The total number of pallets of the shipment
  - The total number of boxes of the shipment, distinguishing between full case orders and unit picked orders.
  - The transporter used for each delivery – this will help us distinguish between rail and road transport
  - The delivery date

We were able to obtain the data of 12 months of deliveries – from July 2008 to June 2009. This represents exactly 340,179 deliveries in this 12-month period.
As mentioned above, the model we want to build will be based on the vehicle-km ratio.

The first information we need is the total distance in km travelled in each phase.
With the list of addresses of clients and using software such as Microsoft MapPoint 2009, we were able to obtain the total distance travelled **D** between the CUS and each client. However, we need to estimate the distances d_1, d_2, d_3 and d_4.

Phase 1:

The number of trucks leaving the CUS to H_1 can be well estimated using registration data done by the security guard: For security reasons, in order to access the CUS, each truck needs to give his plate number and name of its transport company in order to access the loading area. Manual compilation of this data over a period of 3 months will give us a good approximation of the number of trucks travelling on phase 1 over a period of one year.

Unknowns are:

- Distances from CUS to H_1
- Exact itinerary information of trucks leaving the CUS
- Type of vehicle
- Fill rate of each vehicle

Hence, the first assumptions we will make to calculate emissions on phase 1 are:

Phase 1 / A1 All transporters use a first transshipment hub H_1 that is 10km away from the company's distribution centre, therefore, **d_1 = 10km**

Phase 1 / A2 The number of trucks leaving the CUS to H_1 will be estimated at 9040 a year, as per data compilation done with registration information

Phase 1 / A3 d_1 is independent of D

Phase 1 / A4 Only 53' Air Ride Dry Vans with a 3800 cubic ft capacity are used in phase 1

Phase 1 / A5 Transporters reach a 70% fill rate throughout this phase

In summary, the first calculation will be based solely on the number of truck leaving the CUS to H_1.

Phase 2 and Phase 3:

The next calculation will be based on the distance between the CUS and the client, with a distinction between large and small clients as well as distributors.

Differentiating between types of clients will be done based on 'practical knowledge' as well as data available on each of these clients: Each client will be sorted according to this data and will be reviewed manually and will be identified as *Regular Client, Major Client* and *Distributors.*

The transport data obtained by the CUS's information system will be consolidated by clients, using Excel pivot tables. We will estimate the number of equivalent vehicle shipped a year to each client. For each client, we have the total annual volume (or weight) shipped. We can then divide that number by an average load transported by a truck, resulting in the average equivalent number of vehicles per client, as described in the ADEME methodology. Multiplying the number of vehicles by the distance for each client, will result in obtaining each of their vehicle-km ratio.

It is important to note that for example a 53' air ride dry van can carry 3800 cubic ft or 29000 pounds, whichever limit is reached first. As mentioned by Samuelsson & Tilanus (1997) , for product of lower density, the volumetric measures of "vehicle fill" should be considered. For each client, we will compare the ratio between the volume and weight of all deliveries of a year, with the ratio of an optimized loaded van (for example: 3800/29000 as in the case of a 53' van). The number of trucks will vary depending on which limit is reached first, considering an estimated fill rate – the weight or the volume limit.

Unknowns are:

- Exact itinerary (or d_2,d_3 and d_4) of each vehicle
- Type of vehicle used on phase 2 and on phase 3
- Fill rate of each vehicle

On Phase 2, assumptions to be made are:

Phase 2 / A1 Only 53' Air Ride Dry Vans with a 3800 cubic ft capacity are used in phase 2

Phase 2 / A2 Transporters reach a 70% fill rate throughout the shipment

Phase 2 / A3 H2 will be considered 'in the way', meaning that any stop at H2 will not add in distance

Phase 2 / A4 $d_2 = 0.9D$ for *Regular Clients* and *Major Clients*

Phase 2 / A5 $d_2 = D$ for *Distributors*

On Phase 3, assumptions to be made are:

Phase 3 / A1 Only 24' straight trucks with a 1550 cubic ft capacity are used in phase 3

Phase 3 / A2 Transporters reach a 70% fill rate throughout the shipment

Phase 3 / A3 $d_3 = 0.1D$

Phase 3 / A4 All deliveries will travel the distance $d_3 + d_4$, with $d_4 = 0$ for *Major Clients* and = 2km for all *Regular Clients.*

Phase 3 / A5 $d_3 = 0$ for *Distributors*

In summary, the general calculation method will be as follow:

$$E_{outbound} = \sum_{CUS\ to\ H1} V_{1-53'} * d_1 * e_{1-2} + \sum_{\substack{regular\ and\ major\ clients \\ Phase\ 2}} V_{2-53'} * 0.9D * e_{1-2} + \sum_{\substack{regular\ and\ major\ clients \\ Phase\ 3}} V_{3-24'} * 0.1D * e_{3-4} + \sum_{\substack{Distributors \\ Phase\ 2}} V_{2-53'} * D * e_{1-2} + \sum_{regular\ clients} V_{3-24'} * d_4 * e_{3-4}$$

With:

$V_{1-53'}$ = Number of 53' air ride dry vehicles leaving the CUS to go to H1

d_1= the estimated distance between CUS and H1, i.e. 10km

e_{1-2} = Emission factor of GHG of a $V_{1\text{-}53'}$ filled at 70%

$V_{2-53'}$ = Number of 53' air ride dry vehicles for each client on phase 2

D = the distance between the CUS and the client, as given by mapping software

$V_{3-24'}$ = Number of 24' standard vehicles for each client on phase 3

e_{3-4} = Emission factor of GHG of a $V_{3\text{-}24'}$ filled at 70%

d_4 = 2km, or the detour that the transporter has to make in order to reach the CUS's client

The vehicles' characteristics are described in Table 3-1.

Table 3-1: Physical characteristics of vehicles[4]

	Length	Width	Height	Tare weight	GVW	Capacity	Estimated capacity
	(ft)	(in)	(in)	(pounds)	(Pounds)	(Cubic ft)	(Cubic ft)
53' Air Ride Dry Vans	52.5	102	102	15000	44000	3800	2660
53' Air Ride Refrigerated Vans	52.5	97	99	15500	45000	3500	2450
24' Straight truck	24	98	102	10000	26000	1550	1085

To evaluate $e_{1\text{-}2}$ and $e_{3\text{-}4}$, we can use the COPERT III methodology cited by ADEME knowing $e_{\text{fully loaded}}$ and e_{empty} of each type of trucks. The methodology considers:

- No variation in consumption between $e_{\text{fully loaded}}$ and e_{empty} for light vehicle, no matter what load is carried – hence fill rate would be irrelevant
- For all vehicle with maximum capacity > 3.5t, there is an overconsumption of 44% when fully loaded compared to when running empty.

The equation is: $e_{fully\ loaded} = a * e_{empty}$

Where a is 1 for light vehicle and 1.44 for vehicle with maximum capacity > 3.5t

Assuming linear progression, for vehicle with capacity > 3.5t, we can write that for a fill rate **F**:

$$e_{loaded\ at\ F} = e_{empty} + \left(1.44\ \ e_{empty} - e_{empty}\right) * F$$

Or:

$$e_{loaded\ at\ F} = e_{empty}(1 + 0.44 * F)$$

Using values found in Table 2-13, we can estimate both $e_{1\text{-}2}$ and $e_{3\text{-}4}$ and use:

	Average	Average	Empty vehicle	Full vehicle	Maximum
Vehicle type (based on Gross Weight Limit)	**Kg CO_{2eq} per vehicle - km**	**Kg of CO_{2eq} per vehicle - mile**	**Kg CO_{2eq} per vehicle - km**	**Kg CO_{2eq} per vehicle - km**	**(tons)**
11 to 19t – for 24' straight trucks	0.2613	0.420	0.208	0.3	9.79
21.1 to 32.6t – for 53' air ride vans	0.372	0.599	0.302	0.435	16.66

[4] Same as 3

All conditions concerning *Major Clients* and *Distributors* will be incorporated in the Excel model using conditional functions, and are not expressed in the general calculation method shown above.

The last point to be mentioned is that even though similar to the ADEME methodology, this one differs from the fact that e_{fab} and $T_{d.empty}$ were ignored, as this information is not known since the CUS does not own the fleet. Also, the ADEME states that, for companies that subcontract their transport activities:

$$\begin{aligned} &\text{Vehicles} - \text{km} \\ &\qquad = [(\text{tons. km}) \div (\text{Average load of the company'shipment})] \\ &\qquad * (\%\text{ of the load owned by the company}) \end{aligned}$$

It is important to note that we do not know the exact proportion occupied by the CUS's product in a specific truck. Since we are only considering shipments from the CUS, the percentage of the load owned by the company can be bypassed as we are calculating the ratio of *equivalent* vehicle-km for the total volume shipped by the CUS. Lastly, by assuming a fixed fill rate, we can obtain an average load per truck.

Finally, we will also make some variations in the assumptions made to see how it impacts the global results. Using the same spreadsheet, we will simulate the calculation with various fill rates from 10 to 100%, as well as different d_4 ranging from 2km to 10km. Finally, we will test if the proportions given to d_2 and d_3 generate a good estimation. Testing will involve changing, for a fixed fill rate, the value given to both distances: simulation will be done by varying d_2 from 0.9D to D, consequently varying d_3 from 0.1D to 0.

Such simulations will allow us to validate whether the assumptions made create large discrepancies in the calculation, and results will be presented in a later section.

3.1.1.2 *Inbound transportation*

Inbound transportation includes all stock delivered from suppliers to the CUS's distribution centre. In order to evaluate the impact of these stock movements, the information needed is:

a. The location of all suppliers in order to estimate the distance travelled by the merchandise
b. The mode of transport in order to estimate the emissions linked to that mode
c. The weight or volume transported
d. The fill rate of the container / trailer imputable to the distribution centre, i.e., the percentage of the total stock that is owned (or bought) by the distribution centre out of each shipment

The inbound stock comes mainly from Europe, by sea and from the US, by truck. The distances between the suppliers and the CUS can be obtained with the help of mapping software as well.

The data available relative to inbound transportation are not as detailed as the one for outbound. We were able to obtain, aside from the address of the supplier, the following information per supplier:

- The total number of pallets imported
- The total weight of merchandise
- Date of shipment arrival
- Other information not pertinent to our calculation such as container number or invoice number

First, we will aggregate the data by supplier and consolidate the weight shipped for each of them for the year 2008.

Then, for US import, that uses only road transport we will estimate a yearly number of equivalent vehicles shipped – as described in section 3.1.1.1 with the same assumptions:

Inbound / A1 Vehicles have a 70% fill rate (same as for outbound transportation)

Inbound / A2 Only 53' high-cube dry vans are used

Inbound / A3 Any possible re-routing of the vehicles will be ignored: the distance travelled will be considered to be the distance between the supplier and the CUS as given by the mapping software

Hence:

$$E_{inbound,US} = \sum_{Suppliers\ to\ CUS} V_{in-road-53'} * d_{US} * e_{1-2}$$

With:

$E_{inbound,US}$ = Emissions dues to inbound road transportation from the US

$V_{in-road-53'}$ = Number of vehicles by US supplier

d_{US} = Distance between each suppliers and the CUS

e_{1-2} = Emission factor of GHG of a V1 – 53' filled at 70%

For Europe inbound transportation, the method is slightly different. Suppliers in Europe are not all located near a port. Multimodal transport is a reality: A portion of the distance is done by rail or road, until a port is reached. For example, if a supplier is in Paris, France, the distance from Paris to Le Havre (one of the main port used by the CUS's suppliers in France) is done by rail or road. Then, the shipment is loaded on a vessel to cross the Atlantic to reach the port of Montreal. It is finally loaded on a truck to reach the CUS. We need to dissociate both modes in order to obtain a good estimation.

Assumptions to be made are:

Inbound / A4 All distances made to reach a port are done by road on a 53' dry van filled at 70%

Calculation will be done in two parts: the first one will take into account the road transport from the suppliers' warehouse to the closest port and from the Montreal's port to the CUS, and the second one will take into account the transport done by sea.
Equation for the road transportation will be the same as the one for all US shipment. Details on ports' location will be given by the department of transport of the CUS. We will find the distances between suppliers and ports using mapping website such as google map or Map24.

The equation will be:

$$E_{inbound,EU\ road} = \sum_{Suppliers\ to\ port} V_{in\ EU-road-53'} * (d_{supplier-port} + d_{Montreal\ port-CUS}) * e_{1-2}$$

With:

$E_{inbound,EU\ road}$ = Emissions due to inbound road transportation from suppliers to a port and from the Montreal port to the CUS

$V_{in\ EU-road-53'}$ = Number of vehicles by EU suppliers

$d_{supplier-port}$ = Distance from EU supplier to closest port

$d_{Montreal's\ port-CUS}$ = Distance from the Montreal port to the CUS

e_{1-2} = Emission factor of GHG of a V1 – 53' filled at 70%

Calculation for the marine transport will be done based on weight transported, or on the Ton-kilometers ratio identified by McKinnon (2003). The emission factors for sea transport found in the literature are only given in terms of CO_{2eq} / ton-mile or ton-km. Hence, we need to calculate the total weight of merchandise transported by each supplier. Fill rate in this case is not relevant to the calculation. The equation to be used is similar to ***Equation 5***:

$$E_{inbound,EU\ sea} = \sum_{Port\ to\ Montreal\ Port} W_{in-sea} * d_{EU} * e_{sea}$$

With:

$E_{inbound,EU\ sea}$ = Total emissions due to inbound marine transport

W_{in-sea} = Total yearly weight imported by supplier

d_{Europe} = Distance from Suppliers'port in Europe and the port of Montreal

e_{sea} = Emission factor of GHG of waterborne craft

Hence, total emissions due to inbound transportation, $E_{inbound}$ will be:

$$E_{inbound} = E_{inbound,US} + E_{inbound,EU\ road} + E_{inbound,EU\ sea}$$

3.1.2 Transportation of personnel

As seen in the literature review, the information needed in order to calculate GHG emissions due to employees commuting between their home and work are the following (The GHG Protocol, 2006):

1. Employees' data:
    a. Number of employees as well as daily visitors
    b. Number of days worked per year
    c. Highway and city distances driven daily by each employees and each visitor
    d. Mode of transportation (bus, train, car, bike or motorcycle)
    e. Type of car driven and their related emission rate under both city and highway speeds
2. Business related travel data:
    a. Number of trips taken per year
    b. Number of people per trip
    c. Distance travelled per trip
    d. Mode of transportation used
3. Conversion factors from fuel consumption to GHG emissions for each mode of transportation

In order to regroup all information required, two options are available:

a. <u>Survey approach</u>:

   This method is very exhaustive and time consuming. It requires one to build a questionnaire regrouping all information needed (see list above) and then compile the personalized data in order to:

   a. Obtain the total amount of km travelled per year by each employee, to commute to work and on business travel
   b. Calculate the total amount of GHG emitted by each employee, by using the conversion factor correspondent to their mode of transport for their commute to work and their business travel.

   Also, the data correspondent to the visitors will have to be gathered manually, using the visitor log book and identify both the number of km they travelled and the car they used during that travel.

b. <u>Estimation approach</u>:

   This method is not as accurate. However it allows faster compilation of the information required. Instead of asking each employee their personal travel information, we can:

   - Obtain their addresses by using the help of the human resource department and run a program such as MapPoint to obtain the total distance travelled
   - Estimate a percentage of highway and city driving, if needed
   - Estimate a percentage of people that use their car versus public transportation to travel to work. One could use the proportion found in the literature (Statistics Canada, 2008 a)) or a more customized one, based on the rough observations done within the company.
   - Choose an emission factor to estimate emissions based on fuel consumption or distance travelled

For business related travel, one can estimate by asking an administrative assistant how many trip she booked approximately for how many people and to what destination.

As for visitors, we can estimate the total number of visitors in a year by compiling data of one week, assume they travel by car and estimate their distance travelled roughly.

In the context of this research, we will use the **estimation approach.**

The calculation method will be based on ***Equation 3*** for employees travelling by car and based on ***Equation 4*** for employees using public transportation. The emission factors found in the literature (

Table 2-12) will be used for the calculation.

The assumptions to be made are:

Personnel / A1 Every employee travel alone – no carpooling is done

Personnel / A2 An average of 10 visitors a day, that drive 15km in order to reach the site

Personnel / A3 5% of the total distance travelled by the employees is done through public transportation since the location of the site is not easily reachable by bus or subway. We will consider 50% of the distance travelled by subway and 50% by bus.

Personnel / A4 No differentiation will be made between city and highway driving.

Personnel / A5 All employees which names are given by the HR department will be considered as full time employees working 49 weeks a year, or 245 days a year.

Personnel / A6 Other factors such as road congestions, vehicle maintenance or sick leaves will not be taken into consideration.

Personnel / A7 No remote work is done

The second part of the analysis will involve evaluating how the environmental impact would change if more employees carpool, use public transportation or work remotely from their homes. The calculation will take in consideration the number of kilometers driven that would be avoided in all mentioned cases:

- For remote work, assuming for example that office employees work from their home 10 days a years, we will calculate the emissions based on 235 days worked and travelled, instead of 245.
- For carpooling, we will base our calculation on the total distance travelled. For example, if 10% of the night and day shift carpool, we will consider that 10% of the distance travelled by both shift is done using one car instead of two.
- For public transportation, we will also base our calculation on total distance. For example, if 20% of the work force uses public transportation, then emissions will be calculated based on 20% of distance travelled by public transportation (50% bus and 50% subway) and 80% of distance travelled by car.

The result will be presented in a later section.

3.2 Building operations

Estimating GHG emissions related to building operations can be very straightforward. One could draw an energy balance of the site under study by inventorying all equipment (auxiliary, motors, lighting, heating and cooling sources as well as water heating equipments), as well as their power usage, type of energy used and time of operation. This method allows to identify the major end users and can help in determining what energy efficiency project should be prioritized. However, this is not the purpose of this paper.

Another method, less exhaustive, consists in looking at the total energy used by a site. This information can be easily obtained by looking at the energy supplier's invoices or with the help of energy meters, if available.

For the purpose of this research, we will use the invoices of Hydro Quebec and Gaz Metro, energy providers in Quebec, the first one being for electricity and the second, for natural gas. We will take into account the consumption of an entire year.

We will not go in the detail of emissions of each operated appliance: for example, we will not consider the emission of a gas heater on its own, but we will take into account the entire consumption of the building, regardless of where the energy is used.

Equation 1 and ***Equation 2*** as well as emission factors listed in Table 2-11 will be used to calculate total emissions due to the building's energy use.

Assumptions to be made are:

Building / A1 No other source of energy is used in the building's operations other than natural gas and electricity

CHAPTER 4 : CASE APPLICATION

Built in early 2000, the logistic platform under study has been designed to incorporate all logistical activities within the Canadian supply chain of the CUS: the procurement, customer service, IT, finance, transport and distribution departments coexist in this facility. Using the methodology described in the previous section, we will now calculate the CO_{2eq} emissions linked to the considered activities.

4.1 Estimation of emissions of CO_{2eq} with original assumptions

This first section will present the results obtained when calculating the emissions with all assumptions presented in the methodology.

4.1.1 Outbound transportation

Overview of clients and shipment spacial distribution

With over 8,200 clients served between July 2008 and July 2009, the amount of movements linked to the 340,079 deliveries is considerable. This 12-month period will represent the time frame of this study and will be considered implicit throughout.

Using Map Point 2009, we were able to map the addresses to have a spatial distribution of only Canadian clients, as shown in Figure 4-1. The CUS ships also to the US, to clients ordering products online. These orders accounts for only 2.5% of all deliveries, as shown in Table 4-1.

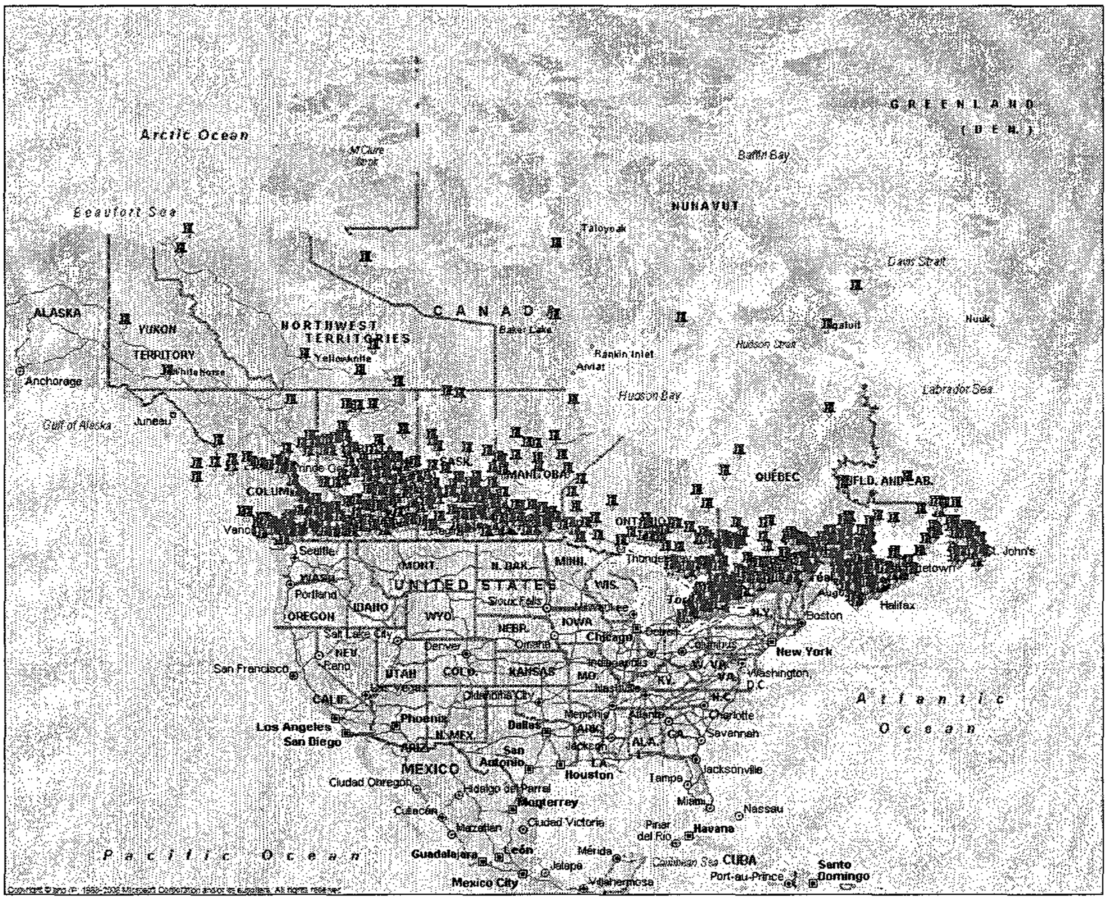

Figure 4-1: Mapping of all Canadian clients

Nearly 70% of all shipments are done between Quebec and Ontario. Western provinces including Alberta and British Columbia account for about 18% of all shipments.

The proportion of clients by region follows the one for deliveries.

As seen in Figure 4-2, a little over 70% of all clients are located in Quebec or Ontario. Alberta and British Columbia account for about 17% of all clients. There is a logical parallel between the number of clients by region and the number of shipment done by region.

Table 4-1: Deliveries of the CUS in North America

	Total number of deliveries	% of total deliveries
USA	**8,452**	**2.5%**
Canada	**331,727**	**97.5%**
Ontario	118,002	34.7%
Quebec	114,558	33.7%
British Columbia	31,901	9.4%
Alberta	29,522	8.7%
Nova Scotia	8,513	2.5%
New Brunswick	8,107	2.4%
Manitoba	7,892	2.3%
Saskatchewan	6,663	2.0%
Newfoundland	4,567	1.3%
Prince Edward Island	1,122	0.3%
Yukon Territory	521	0.2%
Northwest Territories	353	0.1%
Nunavut	6	0.0%
Total	**340179**	**100.0%**

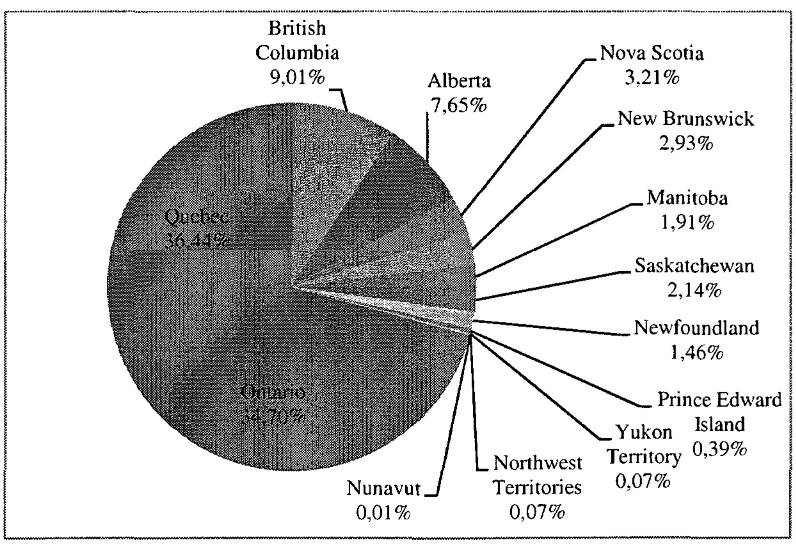

Figure 4-2: Proportion of clients by region in Canada

The last information obtained on the type of clients is whether they are categorized as Major Client, Regular Client or Distributor. Data compilation is shown in Table 4-2.

Table 4-2: Number and percentage of clients by type

	Number of clients	Percentage of total
Distributor	114	1.4%
Major Client	4,620	56.2%
Regular Client	3,485	42.4%

Since manual compilation was done in order to segregate between the three types of clients listed above, results could be slightly affected by wrongful categorization.

Applying methodology to estimate emissions

An Excel master spreadsheet was developed incorporating all parameters listed in the methodology in 3.1.1.1. Formulas stated above were linked to all the parameters we want to modify in order to reflect different scenarios, so that calculation is done automatically.

The structure of the spreadsheet isolates all three phases of outbound transport. Below are all the results compiled.

Initial assumptions are summarized below, in Table 4-3:

Table 4-3: Summary of initial assumptions

				Distance on phase		
	Type of truck	Capacity	Fill rate	Regular Clients	Major Clients	Distributors
Phase 1	53' truck	3,800 cubic ft	70%	10km	10km	10km
Phase 2	53' truck	3,800 cubic ft	70%	90% of D	90% of D	100% D
Phase 3	24' truck	1,500 cubic ft	70%	10% of D	10% of D	0
Detour	24' truck	1,500 cubic ft	70%	2km	0	0

The results are shown in **Erreur ! Source du renvoi introuvable.**.

Table 4-4: Emissions in kg of CO_2eq of outbound transportation with original assumptions

	Emissions in kg of CO_{2eq}				
Fill rate	Phase 1	Phase 2	Phase 3	Detour	Total
70%	35,717	2,199,614	67,029	304	2,302,664

Total emissions of outbound transportation are 2,302,664 kg of CO_{2eq}.

Results show that 95% of emissions are generated during Phase 2, which was to be expected since the greatest distance is travelled at this phase. Phase 3 accounts for 3% of total emissions, whereas Phase 1 accounts for 2% of total emissions. The emissions due to the detour done by the transporter to serve regular clients are negligible. One can question this last finding: if we apply the fact that transporters do a detour for all clients except distributors, emissions go up to 1,068kg of CO_{2eq}, which still represents less than 0.05% of total emissions. This raises another important question: whether d_4 is estimated correctly.

We will see later how emissions vary with different assumptions.

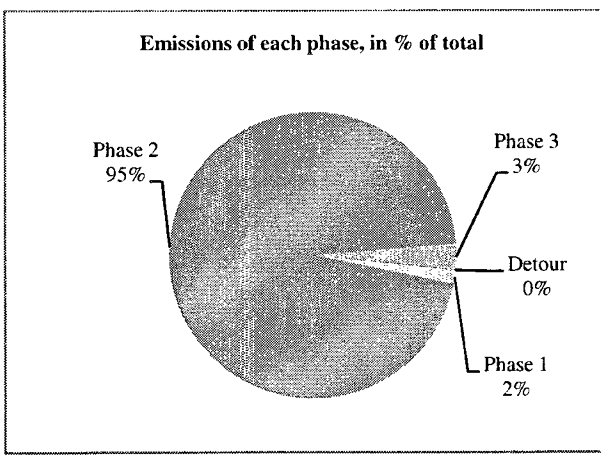

Figure 4-3: Proportional results of emissions for outbound

Also, looking only at Phase 2 and 3, we see that 99.45% of emissions are generated by Canadian deliveries, which is expected since over 97% of clients are located in Canada. However, there is a big discrepancy in ratio of volume/weight shipped and emissions for each province. Figure 4-4 and Figure 4-5 show that proportions between weight and volume shipped are comparable.

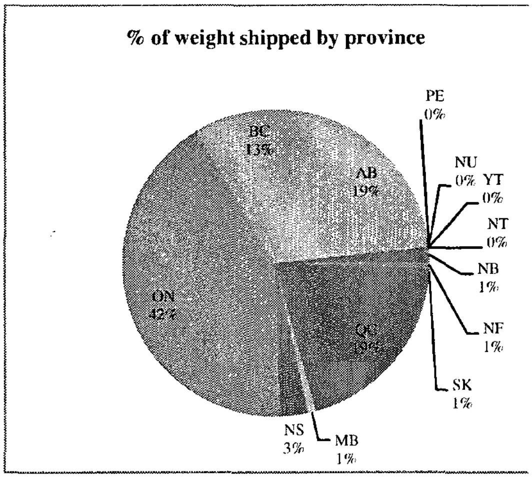

Figure 4-4: Percentage of weight shipped by province

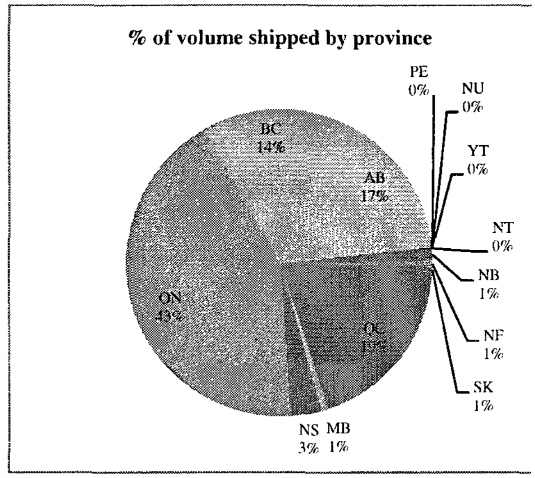

Figure 4-5: Percentage of volume shipped by province

If we look at Figure 4-6, we can see that the proportions of shipments to different provinces do not correspond to the proportions of GHG emissions: for example, British Columbia accounts for 13% of the weight shipped and for 38% of the total emissions in Phase 2 and 3. In the case of Alberta, 19% of the weight is shipped there; generating 43% of the emissions in the two phases. Ontario accounts for 42% of the weight shipped and 12% of the emissions. Quebec, in turn, accounts for 19% of the weight and just 1% of emissions.

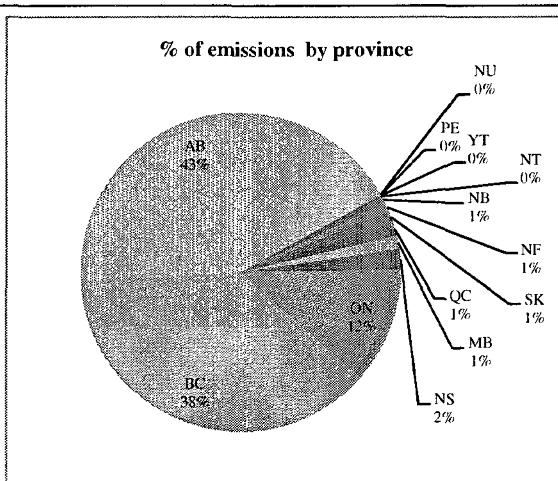

Figure 4-6: Percentage of GHG emissions by province on Phase 2 and 3

The main reason is that distances travelled are much greater for western provinces than for eastern ones, since the CUS is located in the Province of Quebec. This comparative analysis suggests that for vast geographically spread countries such as Canada, it is not the province with the biggest volume shipped out that generates the greatest amount of GHG. The total amount of equivalent 53' trucks calculated in phase 2 for Ontario is 1,370, which is 2.2 times the number of equivalent trucks in Alberta, and yet, shipments in Alberta generate more than 3.5 times more GHG than shipment in Ontario.

Companies should prioritize the optimization of shipment with greater distance in order to have a bigger net saving in emissions. Different scenarios will be presented later in this paper to evaluate such impact.

4.1.2 Inbound transportation

With roughly 20,000 tons of products received yearly from over 60 different suppliers across the world, the CUS has an important inbound shipping activity. The environmental impact of such activity will be evaluated as described in 3.1.1.2.

Most data related to inbound transportation is not yet fully integrated in the CUS's information system. The department of transport, based on master bill of lading and invoices, updates regularly a master list that includes the following:

- Name of supplier
- Address of supplier
- Weight transported at each shipment date
- Data related to the carrier such as its name and containers' number

We were able to obtain the name of the port from which the out of sea shipments departed. The distance between the supplier and the port were found using a website (www.map24.com) that maps distances for European locations.

The distances travelled by sea were obtained using a website that gives the distance in nautical mile between major ports in the world (www.distances.com).

Results are shown in Table 4-5. For confidentiality reasons, the name and exact address of suppliers is not shown. It is to be noted that the distance *Supplier to port* shown for China is the distance between the port of Vancouver and the CUS.

Table 4-5: Distances (road and sea) of out-of-sea suppliers

Supplier	Country of origin	Name of port	Supplier to port (km)	Sea distance (km)	Montreal Port to CUS (km)	Total road distance (km)
1	SPAIN	BILBAO	396	5,725	23	419
2	ITALIE	GENOA	196	7,458	23	219
3	ITALIE	GENOA	163	7,458	23	186
4	ISRAEL	HAIFA	20	9,593	23	43
5	CHINA	HONG KONG	4,891	10,668	N/A	4,891
6	GERMANY	LE HAVRE	749	5,747	23	772
7	GERMANY	LE HAVRE	767	5,747	23	790
8	FRANCE	LE HAVRE	210	5,747	23	233
9	FRANCE	LE HAVRE	670	5,747	23	693
10	FRANCE	LE HAVRE	682	5,747	23	705
11	FRANCE	LE HAVRE	161	5,747	23	184
12	FRANCE	LE HAVRE	986	5,747	23	1,009
13	FRANCE	LE HAVRE	236	5,747	23	259
14	FRANCE	LE HAVRE	226	5,747	23	249
15	FRANCE	LE HAVRE	319	5,747	23	342
16	FRANCE	LE HAVRE	194	5,747	23	217
17	FRANCE	LE HAVRE	288	5,747	23	311
18	FRANCE	LE HAVRE	230	5,747	23	253
19	FRANCE	LE HAVRE	258	5,747	23	281
20	FRANCE	LE HAVRE	210	5,747	23	233
21	FRANCE	LE HAVRE	545	5,747	23	568
22	FRANCE	LE HAVRE	314	5,747	23	337
23	FRANCE	LE HAVRE	314	5,747	23	337
24	FRANCE	LE HAVRE	258	5,747	23	281
25	GERMANY	LE HAVRE	634	5,747	23	657
26	POLAND	LE HAVRE	1,904	5,725	23	1,927
27	SWITZERLAND	LE HAVRE	821	5,747	23	844
28	PORTUGAL	LISBOA	50	5,447	23	73
29	BELGIUM	OOSTENDE	103	5,960	23	126
30	UNITED KINGDOM	SOUTHHAMPTON	122	5,673	23	145
31	UNITED KINGDOM	SOUTHHAMPTON	122	5,673	23	145
32	UNITED KINGDOM	SOUTHHAMPTON	2	5,673	23	25
33	UNITED KINGDOM	SOUTHHAMPTON	231	5,673	23	254
34	UNITED KINGDOM	SOUTHHAMPTON	231	5,673	23	254

For North American suppliers, we used MapPoint to obtain distances to the CUS. They are shown au-dessous:

Table 4-6: Distance between North American suppliers and the CUS

Supplier	State	Country	Distance to CUS (km)
35	GEORGIA	USA	1,947
36	ILINOIS	USA	1,350
37	ILINOIS	USA	1,395
38	KENTUCKY	USA	1,332
39	MASSACHUSSETS	USA	485
40	NEW JERSEY	USA	574
41	NEW JERSEY	USA	776
42	NEW JERSEY	USA	587
43	NEW JERSEY	USA	630
44	NEW JERSEY	USA	630
45	NEW JERSEY	USA	674
46	NEW JERSEY	USA	661
47	NEW JERSEY	USA	652
48	NEW JERSEY	USA	655
49	NEW YORK	USA	623
50	NEW YORK	USA	609
51	NEW YORK	USA	669
52	NEW YORK	USA	662
53	NEW YORK	USA	636
54	NEW YORK	USA	630
55	NEW YORK	USA	608
56	NEW YORK	USA	605
57	OHIO	USA	921
58	OREGON	USA	4,557
59	PENNSYLVANIA	USA	820
60	PENNSYLVANIA	USA	728
61	QUEBEC	CANADA	20.7

By using the equations shown in the methodology with these distances in an Excel spreadsheet, while incorporating as parameters all the assumptions made, we were able to obtain an estimate of emissions as shown in table au-dessous.

The total evaluated emissions for inbound transport is 1,725,592 kg of CO_{2eq}.
It is interesting to see that there is no parallel between the percentage of emissions and the percentage of weight shipped.

Table 4-7: Results for inbound transport

	Number of equivalent 53' trucks	Emissions in kg of CO_{2eq} Road transport	Marine transport	Total	% of total emissions	Total weight shipped (Ton)	% of total weight shipped
BELGIUM	43	2,159	72,537	74,695	4.3%	400	2.0%
CHINA	12	22,458	34,796	57,254	3.3%	107	0.5%
FRANCE	381	56,661	614,032	670,693	38.9%	3,509	17.7%
GERMANY	20	5,970	31,500	37,469	2.2%	180	0.9%
ISRAEL	13	219	34,711	34,930	2.0%	119	0.6%
ITALIE	2	130	3,664	3,794	0.2%	16	0.1%
POLAND	19	14,673	30,971	45,644	2.6%	178	0.9%
PORTUGAL	0	1	43	44	0.0%	0	0.0%
SPAIN	91	15,142	146,967	162,110	9.4%	843	4.3%
SWITZERLAND	0	80	385	464	0.0%	2	0.0%
UNITED KINGDOM	43	4,241	68,375	72,616	4.2%	396	2.0%
CANADA	0.02	0.17	0.00	0.17	0.0%	0	0.0%
USA	1,527	565,878	0	565,878	32.8%	14,071	71.0%
TOTAL	**2,151**	**687,613**	**1,037,979**	**1,725,592**	**100.0%**	**19,820**	**100.0%**

For example, the US accounts for 71% of products shipped, but emissions related to their transport sums up to 32.8%. On the other hand, shipments from France account for about 18% of total weight shipped, but emissions related to their transport represent 38.9% of total emissions. Even if transport by sea is more environmentally friendly, the distances travelled are much larger, which explains these results.

Marine transport accounts for about 60% of total emissions whereas out-of-sea tonnage shipped accounts for 29%. This suggests that companies should deal with closer suppliers. We will see, later in this paper, how emissions could vary if closer suppliers are chosen.

4.1.3 Personnel transportation

With the help of the human resources department, we were able to obtain the list of all permanent and temporary employees working in the company. The list was sent on July 13th, 2008. Any discrepancies in the number of employees or address change between this date and the time of analysis have been ignored. For confidentiality reasons, the information included only their employee number, the postal code of their address and what shift they were on. In total, 363 people work under three different shifts, represented in Figure 4-7.

Using Map Point 2009, we were able to map the addresses to have a spatial representation of employees repartition within the region of Montreal (see Figure 4-8, Figure 4-9 and Figure 4-10). We calculated the distances in km between the DC and each of the employees' postal code. This data allow us to have the total daily distance travelled by each employee (details can be seen in APPENDIX A).

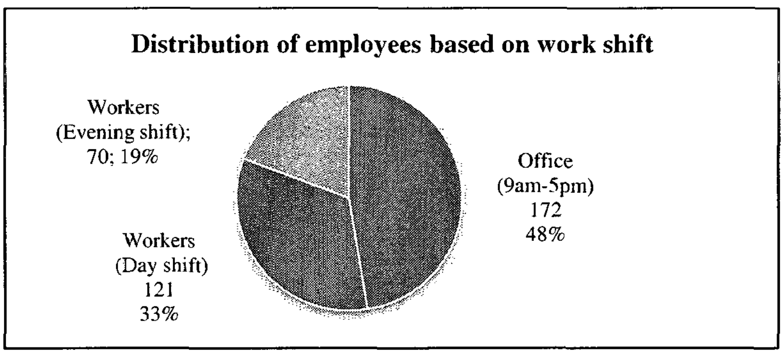

Figure 4-7: Distribution of employees, based on their work shift

We also included visitors in the calculation, as mentioned in the methodology. The next step was to calculate CO_{2eq} emissions. First, we calculated emissions assuming that no public transportation was used. A summary of these results is shown in Table 4-8.

Table 4-8: Emissions from employees and visitors commuting

	Per year	KG per day	KG per year
	Travelled distance (km)	CO_{2eq}. (kg)	CO_{2eq} (kg)
Day Shift Total	1,471,999	1,399	342,678
Evening Shift Total	907,196	862	211,193
Office workers Total	1,865,866	1,773	434,369
Visitors Total	36,750	35	8,555
Grand Total	**4,281,811**	**4,069**	**996,794**

Assuming that every employee and visitor travel by car, results show that about 996,794kg of CO_{2eq} are emitted yearly due to employees and visitors commuting to the site under study,

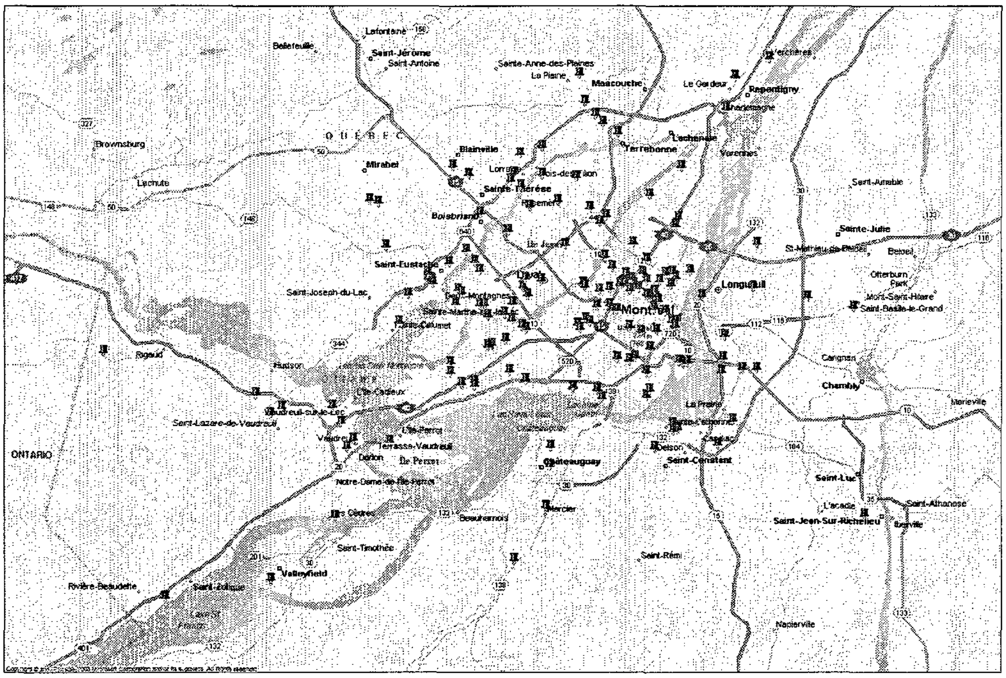

Figure 4-8 : Office employees address mapping

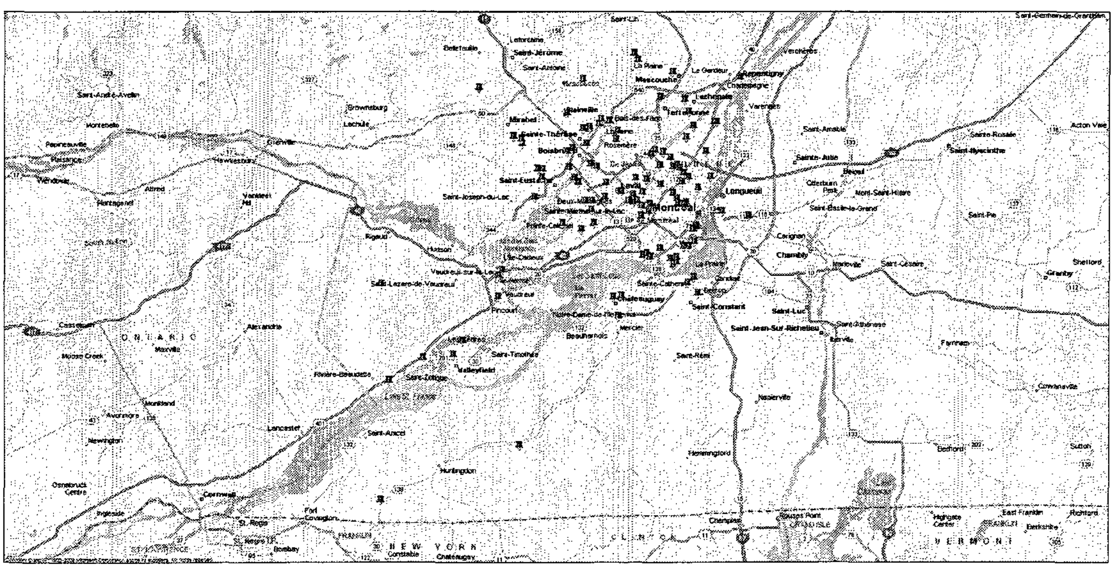

Figure 4-9: Workers (day shift) address mapping

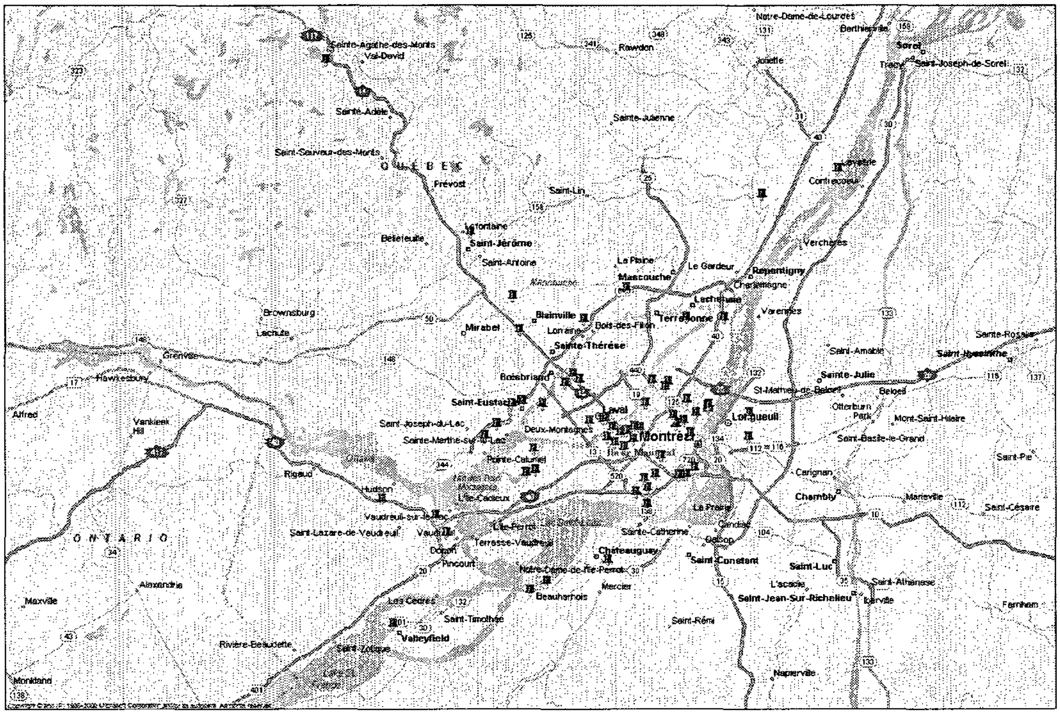

Figure 4-10: Worker (evening shift) address mapping

Results showed that if assumption Personnel / A3 is considered, i.e. 5% of the total distance travelled by employees is done through public transportation, then the yearly emissions would drop by 3.2% to 965,249kg of CO_{2eq}, compared to the only-car travel scenario.

4.1.4 Building operations

The building under study occupies 375,000 square feet and can be divided into two sectors: the warehousing sector, which accounts for 325,000 square feet and the administrative sector, which accounts for 50,000 square feet. It is occupied throughout the year between 7am to midnight, 5 days a week; whereas offices are busy often until 7pm. Overtime might occur occasionally during the weekends. There is also a running cafeteria that provides hot meals to the day shift personnel.

The energy used by the building falls in the ordinary: mainly, energy is used for heating, cooling, lighting and powering auxiliary equipments such as computers and server units. Heating is provided by electrical heating boards in the administrative areas coupled with rooftop units. In the warehouse, heating is provided by commercial air heaters coupled with makeup air units, both using natural gas as energy source.

An energy study was made by a group of consultants in 2007 and showed that more than 40% of the total electricity used was destined for indoor lighting (Table 4-9) and more than 70% of the natural gas used was used for the heating of makeup air (Table 4-10).

Table 4-9: Electricity consumption by End-Use for the CUS

Indoor lighting	2,000,000	kWh	43.49%
Make up air rooftop units	896,000	kWh	19.48%
Computers	630,000	kWh	13.70%
Heating	309,000	kWh	6.72%
Air conditioning	241,000	kWh	5.24%
Other	150,000	kWh	3.26%
Heating of makeup air	122,000	kWh	2.65%
Humidifiers	66,000	kWh	1.44%
Kitchen appliances	66,000	kWh	1.44%
Outdoor lighting	43,000	kWh	0.93%
Battery Chargers	39,000	kWh	0.85%
Domestic water heating	37,000	kWh	0.80%
Total	**4,599,000**	**kWh**	**100.00%**

Table 4-10: Natural gas use at the CUS

Natural gas end use	m^3	% of total
Heating	109,400	27.54%
Heating of makeup air	282,800	71.20%
Kitchen appliances	5,000	1.26%
Total	**397,200**	**100.00%**

We were able to obtain all natural gas consumption as well as electricity consumption from the CUS's energy suppliers' invoices. The span of one year has been used (February 2007 to January 2008), and all values are listed in Table 4-11.

Using ***Equation 1*** and ***Equation 2*** along with emission factors listed in Table 2-11 we were able to obtain the total emission in CO_{2eq} related to stationary combustion.

The total amount of CO_{2eq} emitted by the building in a year is 1,158,802 kg.

The CUS is located in Quebec, and as seen in Table 4-11, total emissions related to electricity use are much smaller than the one of Natural Gas; the main reason being that electricity in Quebec is clean hydro-electricity.

Table 4-11: Summary of monthly energy consumption and GHG emissions over a period of one year

		Electricity	Natural gas	Electricity	Natural Gas				Total Emissions
Energy bill		Consumption	Consumption	CO_{2eq}	CO_2	CH_4	N_2O	CO_{2eq}	CO_{2eq}
Year	**Month**	(kWh)	(Meter cube)	kg	kg	kg	kg	kg	kg
2008	January	415,800	76,221	748	144,134	37.3	3.7	146,076	222,297
2007	February	407,700	67,187	734	127,051	32.9	3.3	128,763	219,491
2007	March	419,400	55,873	755	105,656	27.4	2.7	107,079	195,950
2007	April	369,900	41,428	666	78,340	20.3	2.0	79,396	162,952
2007	May	377,100	14,799	679	27,985	7.3	0.7	28,362	120,824
2007	June	360,000	1,765	648	3,338	0.9	0.1	3,383	43,161
2007	July	373,500	913	672	1,726	0.4	0.0	1,750	5,148
2007	August	383,400	316	690	598	0.2	0.0	606	2,663
2007	September	358,200	880	645	1,664	0.4	0.0	1,687	922
2007	October	358,200	12,788	645	24,182	6.3	0.6	24,508	2,567
2007	November	398,700	49,900	718	94,361	24.5	2.4	95,632	37,296
2007	December	377,100	75,259	679	142,315	36.9	3.7	144,232	145,532
	Total	**4,599,000**	**397,329**	**8,278**	**751,349**	**194.7**	**19.5**	**761,473**	**1,158,802**

The trend of consumption in natural gas (Figure 4-11) shows a great gap between winter months and summer months. Canadian winters are known to be cold, especially in Quebec. Reduction in heating is a difficult option to implement. We can see that from November to April, consumption increases dramatically, indicating the use of heating equipment powered by natural gas. If we look at the entire 12-months period, we can see that 99% of emissions are generated by the use of natural gas (Figure 4-13) whereas in the summer, they account for 68% (Figure 4-14). Between the months of June and September, the consumption of natural gas accounts for less than 1% of the yearly consumption, and still pollutes more than the electricity used in those months – which represents about a quarter of the yearly consumption (Figure 4-14).

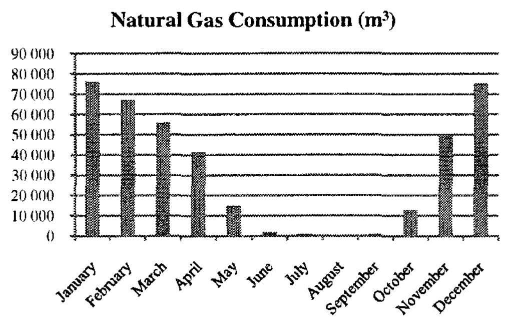

Figure 4-11: Natural gas consumption over a year in m^3

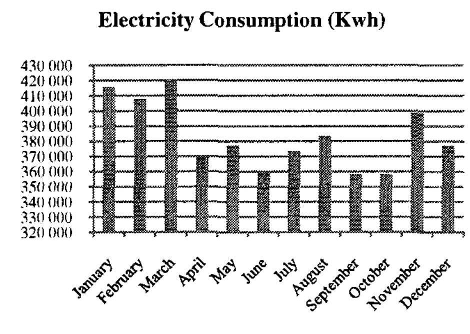

Figure 4-12: Electricity consumption over a year in Kwh

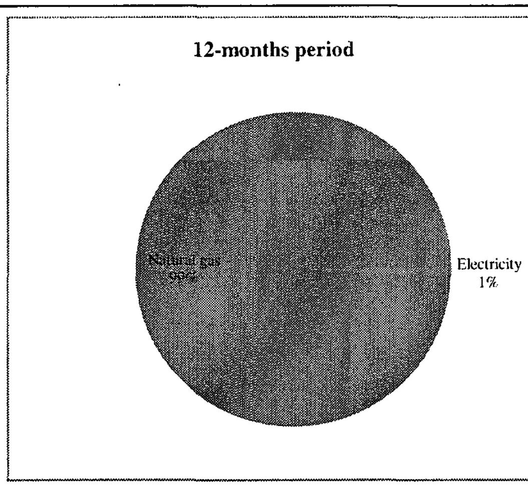

Figure 4-13: Building's emissions of GHG for a 12-months period

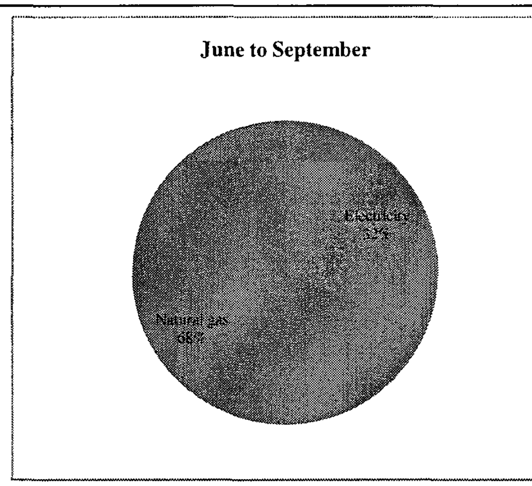

Figure 4-14: Building's emissions of GHG in the summer

Over 99% of the use of Natural Gas is for space heating, generating also over 99% of the GHG emissions. National averages found in the literature showed that in the Commercial and Institutional Sector, space heating accounted for about 49% of the GHG emissions and more specifically, in the Transport and Warehousing sector, they accounted for 63% of emissions (see Figure 2-9 and Figure 2-14). The national average for use of natural gas as energy for space heating in the TWA sector is of 73% (Figure 2-18), compared to over 90% in the case of the CUS. In conclusion, it is very difficult to draw conclusions if only national averages are considered – energy type and end use vary from a province to another and from a company to another.

In conclusion, this analysis suggests that companies should pay a close look at their heating strategies in the winter. As seen in the literature revue, different methods can be helpful in reducing the consumption of natural gas, including centralizing the controls of heat and ventilation, reducing set point temperature in periods of zero occupation or improving insulation of the building (Yoders, 2006). In the case of electricity, even if less pollutant in Quebec, companies can still reach better performance when using more efficient equipment (Aker, 2008). We will estimate later in this paper, the savings in emissions that the CUS could make if energy efficiency projects are implemented.

4.1.5 Global results and comparison

The goal of this paper was to benchmark the various sectors selected in terms of GHG emissions. Comparing all obtained results will allow us to determine the sector of a logistic platform that generates more GHGs. With all original assumptions listed in the methodology, we found that the transportation of goods is the biggest generator of GHG: outbound transportation accounts for 37.4% of total emissions, whereas inbound transportation accounts for 28% of total emissions. Personnel transportation represents 15.7% of total emissions and emissions due to the building's activities account for 18.8% of the total emissions, as seen in Table 4-12 and Figure 4-15.

These results can help management committees in their establishment of environmental strategies.

Table 4-12: Total emissions of the CUS in kg of CO_{2eq}

	Emissions in kg of CO_{2eq}	% of total
Outbound Transportation	2,302,664	37.4%
Inbound Transportation	1,725,592	28.0%
Personnel Transportation	965,249	15.7%
Building's Operations	1,158,802	18.8%
Total	**6,152,307**	**100.0%**

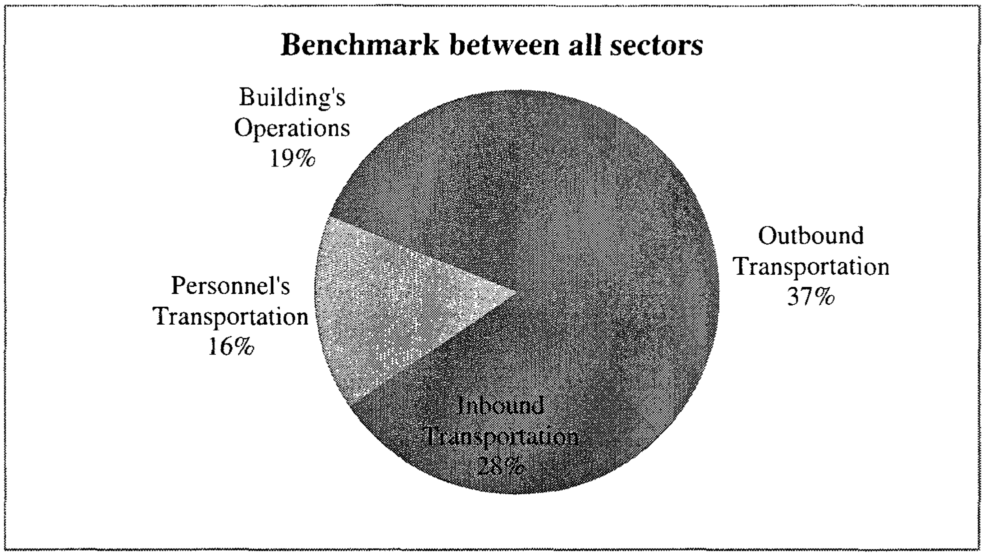

Figure 4-15: Proportion of emissions of GHG in the case of the CUS

We will see in the next section, how, by varying parameters in all sectors, we can reduce emissions. We will evaluate what elements allow the biggest reduction in GHG emissions and also test some of the assumptions made originally in order to see how, by changing them, they impact the results.

4.2 Estimation of emissions of CO_{2eq} with variable assumptions

Initial results were calculated based on fixed assumptions. They give us a rough estimate of the amount of CO_{2eq} emitted by the various sectors of a logistic platform. In this section, we will evaluate how these emissions vary when assumptions change. The goal of this exercise is to lead us in determining where efforts should be put in order to decrease the global environmental impact of the CUS.

4.2.1 Outbound transportation

The first sector we will analyze is Outbound Transportation. With our original assumptions, it accounted for 37.4% of total emissions. How will this rate be affected if we change the parameters in the original calculations? We will look at different scenarios: First, we will vary our initial assumptions in order to test their validity and estimate the margin of error possible. Second, we will analyze the impact of increased fill rate on outbound shipment as well as evaluate the impact of an increased use of rail for western provinces.

4.2.1.1 *Validation of original assumptions*

(i) *Impact of fill rate and distance on Phase 1*

Phase 1, under original assumptions, accounted for 35,717 kg of CO_{2eq}, or 1.55% of total outbound emissions. We assumed a fixed distance of 10km between the CUS and the hubs of the various subcontracted transporters. The impact of Phase 1 is negligible compared to the grand total; however, in order to validate the original assumptions, we calculated the emissions on phase 1 with different values of d_1.

Results are shown in table au-dessous:

Table 4-13: Emission in kg CO_{2eq} on Phase 1, with variable d_1

Fill rate	Number of equivalent 53' trucks	CO_2eq emissions (kg) with **d_1=10km**	CO_2eq emissions (kg) with **d_1=5km**	CO_2eq emissions (kg) with **d_1=15km**
70%	9,040	**35,717**	**17,859**	**53,576**

The CUS is located in an industrial area; making transporters' hubs relatively close. We can see that by increasing d_1 to 15km, emissions go up to 53,576kg of CO_{2eq}, which would represent 1.54% of total emissions of total outbound transportation. Margin of error is small; hence we can consider our initial assumption as valid.

It is interesting to see the impact that the fill rate has on the number of trucks in Phase 1. Increasing fill rate by 5% on Phase 1 decreases the number of trucks by 603 per year, and emissions, at d_I = 10km, is reduced by 2,381kg of CO_{2eq}. Detailed results are shown in APPENDIX C.

(ii) *Impact of detour distance*

Another factor that was taken into consideration in the total emissions calculation of the CUS was the extra distance a trucker has to make in order to drop a client's shipment – called the detour distance and originally estimated at 2km. This detour distance was incorporated in the calculation of only *Regular Clients.* These clients are not part of a chain of stores, and therefore, we assumed they were not in the path of a transporter's itinerary. In the original calculation, the impact of the detour distances was calculated to be 304kg of CO_{2eq} per year, which represents 0.013% of the total impact of outbound transportation. This result is negligible. In order to test the assumption that only Regular Client were imposing a detour distance to transporters, we calculated the impact of a detour of 2km for all clients – *Regular Clients, Major Clients* and *Distributors*: The impact rose to 1,068kg of CO_{2eq}, which is 3.5 times the amount of CO_{2eq} found in original calculation, but still represented about 0.05% of total emissions. The margin of error is very low if one accounts a detour to a portion of clients or to all clients of the CUS. For this matter, the simulations done with different values of d_4 will be applied only to *Regular Clients*, as originally stated.

Table 4-14 and Figure 4-16 show the results of simulations done with variable fill rate values and variable d_4 values. At a 70% fill rate and d_4 = 10km, emissions rise to 1,521kg of CO_{2eq}. This is about 5times the amount found with a value of 2km, but still less than 0.7% of total outbound transportation emissions.

Table 4-14: Impact in kg of CO_{2eq} with variable fill rate and values of d_4

	Values of d_4			
Fill rate (%)	2km	4km	6km	10km
10	1,698	3,397	5,095	8,492
20	885	1,770	2,655	4,426
30	614	1,228	1,842	3,070
40	479	957	1,436	2,393
50	397	794	1,192	1,986
55	368	735	1,103	1,838
60	343	686	1,029	1,715
65	322	644	966	1,611
70	304	609	913	1,521
71	301	602	903	1,505
72	298	596	893	1,489
73	295	589	884	1,474
74	292	583	875	1,459
75	289	578	866	1,444
76	286	572	858	1,430
77	283	566	849	1,416
78	280	561	841	1,402
79	278	556	833	1,389
80	275	550	826	1,376
85	263	527	790	1,316
90	253	505	758	1,263
95	243	486	729	1,216
100	235	469	704	1,173

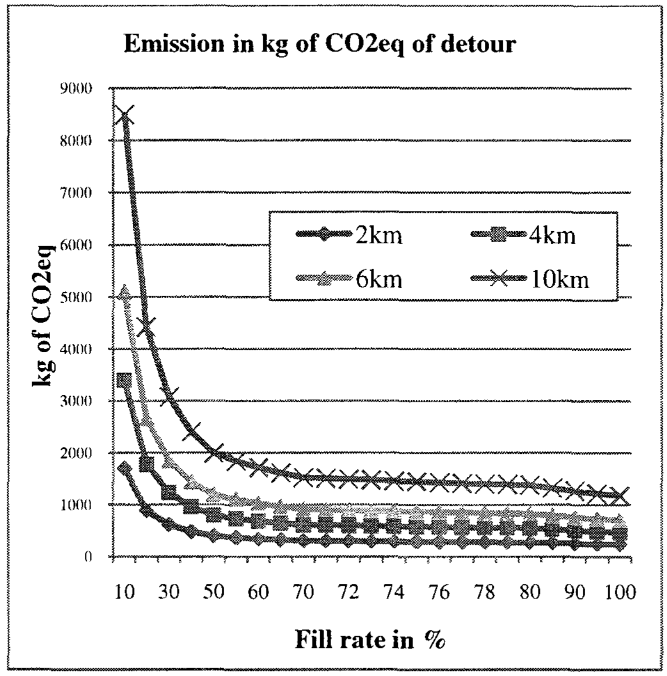

Figure 4-16: Emissions in kg of CO_{2eq} for variable fill rate and values of d_4

This is still negligible and therefore, one could potentially ignore the impact of any detour that a transporter could do in the evaluation of GHG emissions of outbound transportation.

Also, in the best case scenario, if for 2km, transporters optimize their fill rate from 70 to 100%, the savings in CO_{2eq} emissions are of 69kg – which, again, is negligible.

(iii)*Impact of varying distances d_2 and d_3*

We have seen that Phase 2 accounted for about 95% of total emissions in outbound transportation, and Phase 3 only 3%. One could question whether or not distances were well estimated. Originally, we estimated that d_2 was 90% and d_3 10% of D. In the case of shipment in British Columbia for example, D can be very large, resulting in an over evaluation of d_3 leading to a wrong evaluation of CO_{2eq} emissions. In this section, we will present the results of simulations varying the values of d_2 and d_3 and we will evaluate their impact.

We can see that in Table 4-15, if d_2 is considered equal to D, the total emissions on Phase 2 and 3 will decrease by 0.8%. Again, the margin of error is small when debating on the value to be given to d_2 and d_3. Hence, we can consider our original assumption as acceptable.

Table 4-15: Evaluation of the impact in kg of CO_{2eq} of varying d_2 and d_3

	Emissions on Phase 2	Emissions on Phase 3	Emissions due to detour (d_4=2km)	Total Emission in CO_{2eq} (**EXCLUDING** Phase 1)	% of original scenario
d_2=0.90D	2,199,614	67,029	304	2,266,947	100.0%
d_2=0.91D	2,204,485	60,326	304	2,265,116	99.9%
d_2=0.92D	2,209,357	53,623	304	2,263,284	99.8%
d_2=0.93D	2,214,229	46,920	304	2,261,453	99.8%
d_2=0.94D	2,219,100	40,217	304	2,259,622	99.7%
d_2=0.95D	2,223,972	33,514	304	2,257,790	99.6%
d_2=0.96D	2,228,843	26,812	304	2,255,959	99.5%
d_2=0.97D	2,233,715	20,109	304	2,254,128	99.4%
d_2=0.98D	2,238,586	13,406	304	2,252,297	99.4%
d_2=0.99D	2,243,458	6,703	304	2,250,465	99.3%
d2=D	2,248,330	0	304	2,248,634	99.2%

4.2.1.2 *Measuring the impact of fill rate*

This following section will evaluate the impact of varying fill rates on overall emissions of outbound transportation.

(i) *Assuming variable fill rate on all shipments*

Simulations were done with fill rate varying between 10 and 100% on all phases and are shown in Figure 4-17. The greatest drops in emissions are when trucks have a fill rate between 10 and 60%: Total emissions drop by:

- 47.9% when increasing fill rate from 10 to 20%.
- 30.7% when increasing fill rate from 20 to 30%
- 22.1% when increasing fill rate from 30 to 40%
- 17% when increasing fill rate from 40 to 50%
- 13.7% when increasing fill rate from 50 to 60%
- 11.4% when increasing fill rate from 60 to 70%

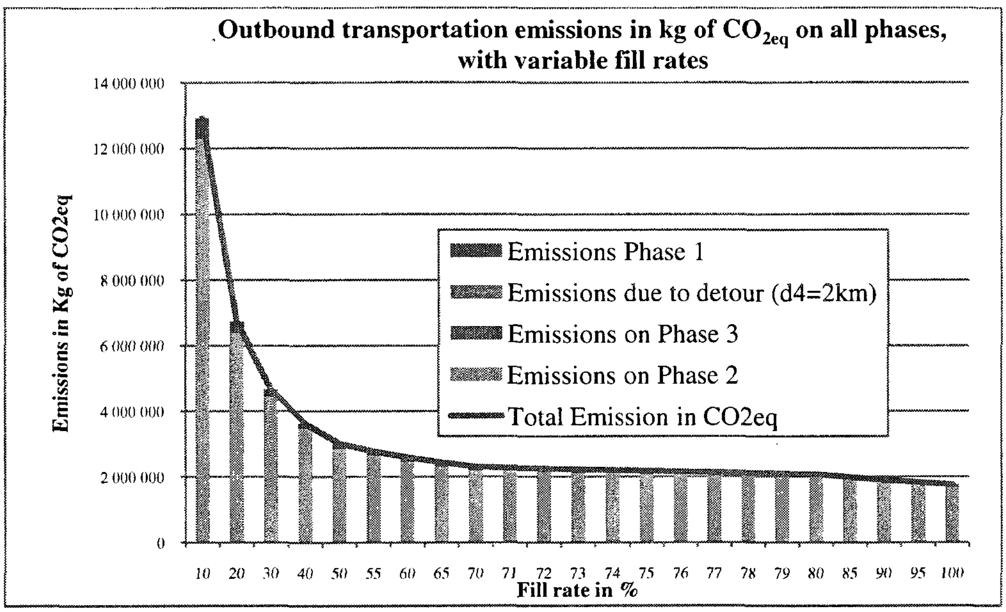

Figure 4-17: Outbound transportation emissions in kg of CO_{2eq} with variable fill rates

An incremental analysis was done starting at a fill rate of 70% up to 80%, shown in Table 4-16. The goal was to evaluate the drop in emissions if fill rate was increased by only 1%. On average, each percentage gained in fill rate, is equivalent to a reduction of 1% in emissions: for example, if fill rate is at 71%, total outbound emissions is reduced by 24,908kg – which represents 1.1% of total emissions generated at a 70% fill rate.

Also, a 5% incremental analysis between 80% and 100% fill rate is shown in the table. Although more difficult to reach, an 85% fill rate would allow a decrease of 13.6% in emissions compared to the original results and a 95% fill rate would allow a drop of 20.2% in emissions compared to a 70% fill rate.

Table 4-16: Results of impact of incremental fill rate analysis on CO_{2eq} emissions

Fill rate variation	Total Emission in CO_{2eq}	kg of CO_{2eq} saved compared to a 70% fill rate	Drop in emissions compared to a 70% fill rate
70	2,302,664	0	0%
71	2,277,756	24,908	1.1%
72	2,253,541	49,123	2.1%
73	2,229,989	72,675	3.2%
74	2,207,073	95,591	4.2%
75	2,184,768	117,896	5.1%
76	2,163,051	139,613	6.1%
77	2,141,897	160,767	7.0%
78	2,121,286	181,378	7.9%
79	2,101,197	201,467	8.7%
80	2,081,610	221,054	9.6%
85	1,990,587	312,077	13.6%
90	1,909,678	392,986	17.1%
95	1,837,286	465,378	20.2%
100	1,772,133	530,531	23.0%

Another interesting aspect of increasing fill rate, is evaluating the number of trucks that could potentially be removed from the roads. Figure 4-18 and Figure 4-19 show the trend in number of 53' and 24' trucks when varying fill rate. An increment in 1% in fill rate leads to the elimination of 46 trucks on phase 2 and 93 trucks on phase 3.

These results concur with what was found in the literature review: the improvement in cube utilization reduces traffic levels, hence congestions, which leads to decrease in GHG emissions (McKinnon A. C., 2000).

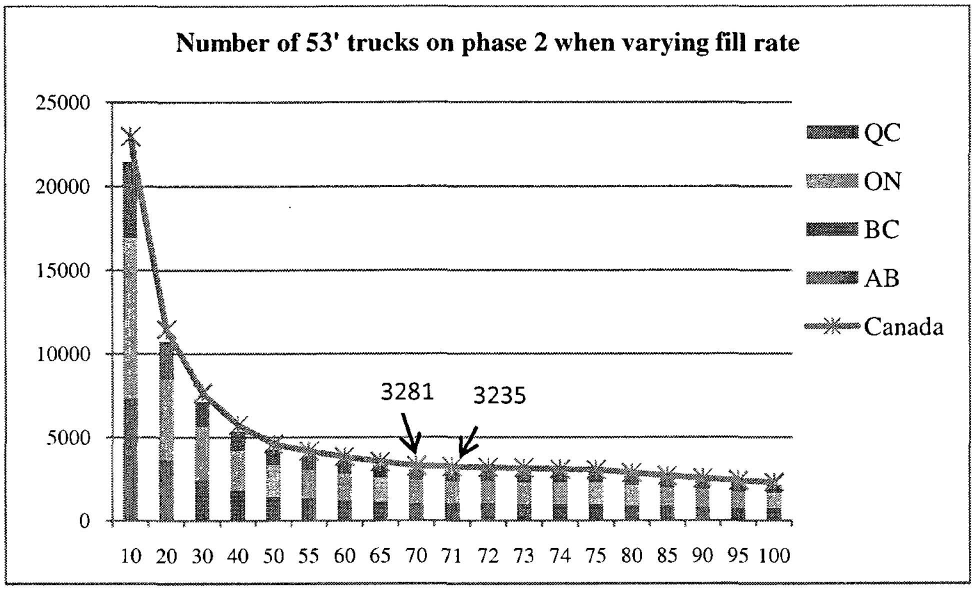

Figure 4-18: Number of 53' trucks on phase 2 when varying fill rate

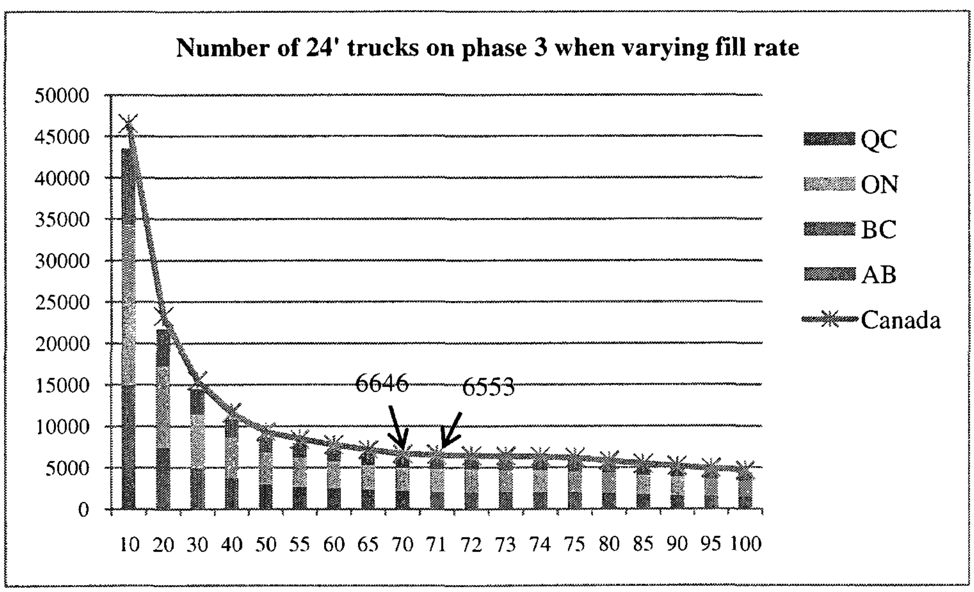

Figure 4-19: Number of 24' trucks on phase 3 when varying fill rate

(ii) *Assuming variable fill rate on shipments to Alberta and British Columbia only*

As seen in section 4.1.1, at a 70% fill rate, Alberta and British Columbia accounts for 81% of total emissions of outbound transportation compared to only 32% of total weight shipped. It is only logical to analyze in more details the emissions related to shipments in these provinces, as they are the biggest CO_{2eq} generators in outbound transportation.

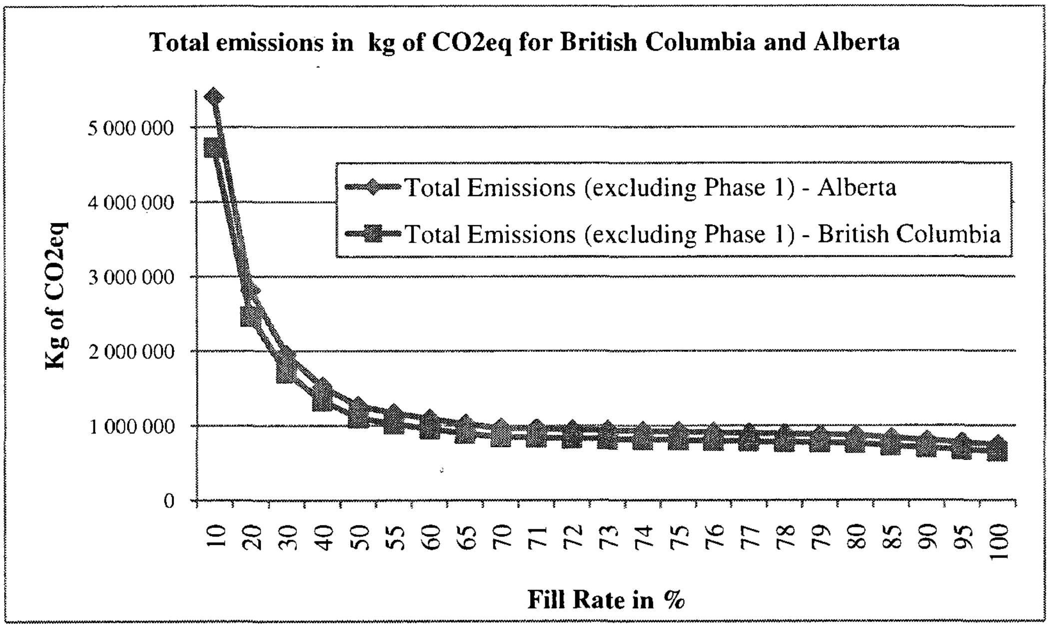

Figure 4-20: Emissions in kg of CO_{2eq} of shipments to Alberta and British Columbia

Figure 4-20 shows the emissions in kg of CO_{2eq} of outbound transportation of both provinces excluding Phase 1. It is interesting to see that the trend is the same as Figure 4-17: The biggest drop in emissions occurs when fill rate is improved from 10 to 20%. Starting at a fill rate of about 60%, the decrease is not as significant, suggesting that transporters have to insure at least a 60% fill rate when shipping to the west.

When analyzing incremental improvement in fill rate between 70 and 80%, we also see that on average, every percent gained in fill rate is equivalent to about a percent of reduced emissions compared to the original assumptions, as seen in Table 4-17.

However, these savings represent 78.4% of the total savings in kg of CO_{2eq} shown in Table 4-16 at a fixed fill rate: for example, at a 74% fill rate, for total outbound transportation, the total amount of kg of CO_{2eq} avoided is 95,591kg compared to emissions at a 70% fill rate. 78.4% of this amount (74,913kg) represents what was saved only on shipment to British Columbia and Alberta.

Table 4-17: Incremental analysis in fill rate for Alberta and British Columbia

	Alberta			British Columbia			Both Provinces	
Fill rate	**Total Emissions (excluding Phase 1) (kg of CO_{2eq})**	**Drop in emissions compared to a 70% fill rate (kg of CO_{2eq})**	**Drop in emissions compared to a 70% fill rate**	**Total Emissions (excluding Phase 1) (kg of CO_{2eq})**	**Drop in emissions compared to a 70% fill rate (kg of CO_{2eq})**	**Drop in emissions compared to a 70% fill rate**	**Total saving (kg of CO_{2eq})**	**Drop in emissions compared to a 70% fill rate**
70	966,895	0	0%	846,271	0	0%	0	0.0%
71	956,486	10,409	1.1%	837,160	9,110	1.1%	19,520	1.1%
72	946,366	20,529	2.1%	828,303	17,968	2.1%	38,497	2.1%
73	936,523	30,372	3.1%	819,688	26,583	3.1%	56,954	3.1%
74	926,947	39,948	4.1%	811,306	34,964	4.1%	74,913	4.1%
75	917,625	49,270	5.1%	803,148	43,123	5.1%	92,392	5.1%
76	908,549	58,345	6.0%	795,204	51,067	6.0%	109,412	6.0%
77	899,709	67,186	6.9%	787,467	58,804	6.9%	125,990	6.9%
78	891,095	75,799	7.8%	779,928	66,343	7.8%	142,142	7.8%
79	882,700	84,195	8.7%	772,580	73,691	8.7%	157,886	8.7%
80	874,514	92,380	9.6%	765,415	80,855	9.6%	173,236	9.6%
85	836,475	130,419	13.5%	732,122	114,149	13.5%	244,568	13.5%
90	802,663	164,232	17.0%	702,528	143,743	17.0%	307,975	17.0%
95	772,410	194,485	20.1%	676,049	170,222	20.1%	364,707	20.1%
100	745,182	221,713	22.9%	652,218	194,053	22.9%	415,766	22.9%

It is also interesting to see the impact of increased fill rate on the number of trucks. An increase of 1% in fill rate in trucks leaving for western provinces results in:

- About 14 fewer 53' trucks for both British Columbia and Alberta on Phase 2
- About 29 fewer 24' trucks for both British Columbia and Alberta on Phase 3

Table 4-18: Impact of fill rate on the number of trucks leaving to Alberta and British Columbia

	Alberta		British Columbia	
Fill rate	Number of 53' trucks	Number of 24' trucks	Number of 53' trucks	Number of 24' trucks
70	606	1,202	443	942
71	598	1,185	436	929

The environmental impact of having 14 fewer trucks going to Alberta and British Columbia is greater than having 20 fewer trucks going to Ontario. APPENDIX E shows the detailed results regarding the impact of fill rate on the number of trucks, by province.

4.2.1.3 *Measuring the impact of using rail for shipments to Alberta and British Columbia*

Another assumption made for the calculation of total outbound emissions was that all transportation was made by road. For vast countries such as Canada, the use of rail is a great environmental alternative to road transport. The last scenario presented herein is the one where rail is used in Phase 2 for all shipments to Alberta and British Columbia. The emission factor for rail found in the literature

Table 2-12), is expressed in kg of CO_{2eq} / ton-mile. Using a similar equation to ***Equation 5***, we can obtain an estimation of CO_{2eq} by incorporating the rail emission factor expressed in kg CO_{2eq} / ton-km as seen in

Table 2-12. We then compared the findings to the original calculations found in 4.1.1. Results are shown au-dessous:

Table 4-19: Comparison between emissions generated by road and multimodal transport

	Phase 2 - Rail	Phase 3	Detour	**Multimodal (Total)**	**Phase 2 - Road**	Phase 3	Detour	**Road (Total)**
AB Total	350,761	20,554	13	**371,328**	946,327	20,554	13	966,895
BC Total	293,831	20,528	12	**314,370**	825,731	20,528	12	846,271
Total	**644,591**	**41,083**	**25**	**685,699**	**1,772,058**	**41,083**	**25**	**1,813,166**

The potential decrease in emissions of CO_{2eq} by switching to rail in phase 2 is of 1,127,467 kg. This represents nearly 49% of the total emissions of outbound transportation – all province included, and about 18.3% of the total emissions estimated for the CUS. The use of rail can dramatically decrease the GHG emissions in transportation. These results concur with studies found in the literature: The use of rail has huge potential in terms of decreasing the environmental impact of freight transport (Ramanathan, 2000; Steenhof, Woudsma, & Sparling, 2006; McKinnon A. C., 2003) . However, also cited in the literature were some downsides related to rail: they include longer delays and limited scheduling flexibility or lack of rail tracks (EPA, 2004). Some surveys showed that shippers are biased when it comes to the use of rail because of all these drawbacks and sometimes because of the nature of the product to be shipped (Patterson, Ewing, & Haider, 2008; Danielis & Marcucci, 2007). McKinnon A.C. (2003) still considers that realistically, road transport will remain predominant. However, with all the global environmental pressures, transport strategies of companies could change, and it will be up to high executives to commit to more sustainable transport practices. Comparative studies such as this one can back up their decisions in switching to rail.

4.2.2 Inbound transportation

With 28% of the total CUS' emissions, inbound transportation is the second largest emitting sector. The original results showed that France and the USA were the two biggest suppliers, accounting for nearly 72% of the total emissions related to inbound transportation. As seen in Figure 4-21, 71% of volume shipped comes from the USA, which generates 32.8% of emissions. France, on the other hand, accounts for 17.7% of the total volume imported, but emissions related to French shipments account for 38.9%. The scenario proposed consists in evaluating the savings in emissions if French production is shipped to the USA, in New Jersey.

By taking the total weight shipped annually from France, and assuming it is transferred to a location in New Jersey, at 630km from the CUS, we were able to calculate the equivalent number of 53' trucks, with an assumed fill rate of 70%. Results showed that:

- The number of trucks from the USA increased from 1,527 to 1,907
- Emissions decreased from 1,725,692 to 1,149,659 kg of CO_{2eq}. for a total estimated saving of 576,033kg of CO_{2eq}

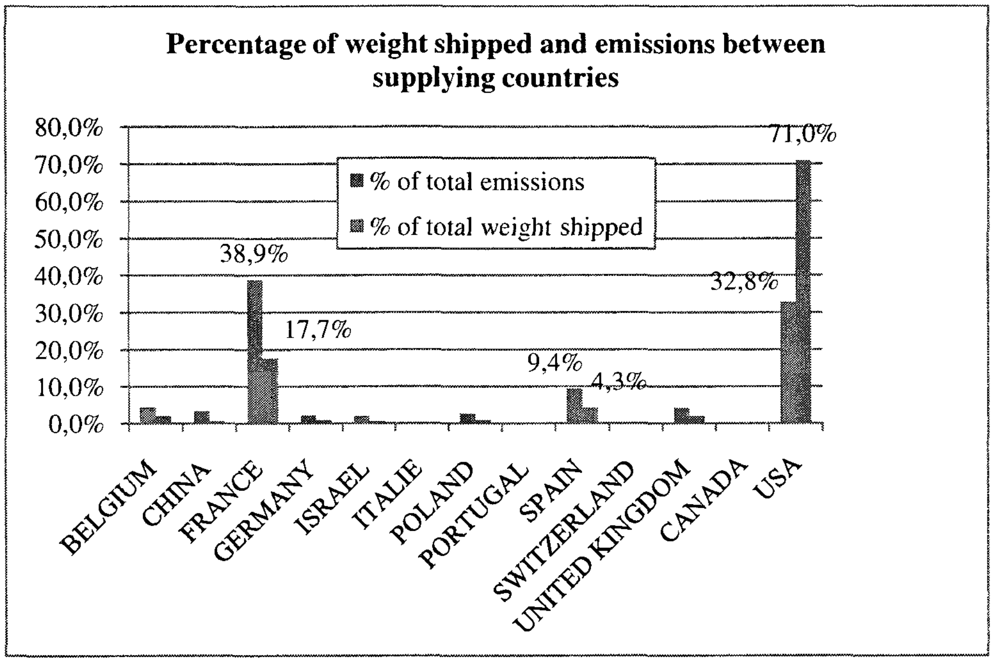

Figure 4-21: Percentage of weight shipped and emissions by supplying countries

If we limit ourselves with these results, we can clearly see that having closer suppliers leads to less environmental impact when it comes to transport, which confirms the findings of Holzafpel (1995): by choosing closer suppliers, a significant reduction in emissions could be reached. However, as mentioned by McKinnon (2003), strategic decisions relating to numbers, locations, and capacity of factories, warehouses, shops and terminals as well as commercial decisions on product sourcing are difficult to modify once established.

In addition, one needs to consider the type of energy used by closer supplier to power production. In this case, the electricity production in New Jersey is made by coal-based power plants, whereas in France, electricity is nuclear, which is much cleaner in terms of emissions.

4.2.3 Personnel transportation

The daily commute of personnel to the CUS accounts for about 16% of the total GHG emissions, or 965,249kg of CO_{2eq}. One of the incentives that a company has to promote greener transportation or allow more remote work is to offer better working conditions and therefore, retain their employees. There is no big direct monetary incentive; however, preserving a good public image of a company is of crucial importance.

The initial assumptions made included no remote work allowed and only 5% of the workers used public transportation. Simulations were done varying both the percentage of people using public transportation and the number of days workers could work from home, and results are shown in Table 4-20. Highlighted is the calculation with original assumptions.

Table 4-20: Results in kg CO_{2eq} obtained by varying both percentage of distance travelled by public transportation and allowing remote work for office workers

% of distance travelled through public transportation	Number of days of remote work allowed per person										
	0	10	20	30	40	50	60	70	80	90	100
0%	996,794	979,065	961,336	943,606	925,877	908,148	890,418	872,689	854,960	837,230	819,501
5%	965,249	948,085	930,922	913,758	896,595	879,432	862,268	845,105	827,941	810,778	793,615
10%	933,703	917,105	900.508	883.911	867,313	850,716	834,118	817,521	800,923	784,326	767,728
20%	870,611	855,146	839,680	824,215	808,749	793,283	777,818	762,352	746,887	731,421	715,956
30%	807,520	793,186	778,852	764,519	750,185	735,851	721,518	707,184	692,850	678,517	664,183
40%	744,428	731,226	718,025	704,823	691,621	678,419	665,217	652,016	638,814	625.612	612,410
50%	681,337	669.267	657,197	645,127	633,057	620,987	608,917	596,847	584,777	572,707	560.637
60%	618,245	607,307	596,369	585,431	574,493	563,555	552,617	541,679	530,741	519,803	508,865
70%	555,153	545,347	535,541	525,735	515,929	506,123	496,316	486.510	476,704	466,898	457,092
80%	492,062	483,388	474,713	466.039	457,365	448,690	440,016	431,342	422,668	413.993	405,319
90%	428,970	421,428	413,885	406,343	398,801	391,258	383,716	376,174	368.631	361,089	353,546
100%	365,879	359,468	353,058	346.647	340.237	333,826	327,416	321,005	314,595	308,184	301,774

Table 4-21 shows the net saving in tons of CO_{2eq} compared to the only-car scenario when both factors are varying.

Equivalencies shown in Table 4-22 can be understood as follows:

- Having 5% of total distance travelled by public transportation leads to as much reduction in CO_{2eq} emission as allowing office workers to work remotely 18 days a year

- Having 30% of total distance travelled by public transportation leads to as much reduction in CO_{2eq} emission as allowing office workers to work remotely 107 days a year

Table 4-21: Net saving in ton CO_{2eq} when varying the use of public transportation and increasing the number of days of remote work allowed

% of distance travelled through public transportation	Days of remote work allowed per person										
	0	10	20	30	40	50	60	70	80	90	100
0%	0	18	35	53	71	89	106	124	142	160	177
5%	32	49	66	83	100	117	135	152	169	186	203
10%	63	80	96	113	129	146	163	179	196	212	229
20%	126	142	157	173	188	204	219	234	250	265	281
30%	189	204	218	232	247	261	275	290	304	318	333
40%	252	266	279	292	305	318	332	345	358	371	384
50%	315	328	340	352	364	376	388	400	412	424	436
60%	379	389	400	411	422	433	444	455	466	477	488
70%	442	451	461	471	481	491	500	510	520	530	540
80%	505	513	522	531	539	548	557	565	574	583	591
90%	568	575	583	590	598	606	613	621	628	636	643
100%	631	637	644	650	657	663	669	676	682	689	695

Table 4-22: Equivalencies between using public transportation and allowing office workers to work remotely from their homes

% distance travelled through public transportation	Number of days of remote work allowed per person				
	0	18	35	71	107
0%	996,794	964,881.64	934,741	870,916	807,091
5%	965,249				
10%	933,703				
20%	870,611				
30%	807,520				

Another scenario that was analyzed is the possibility of carpooling.

Since workers from the day and evening shift have exactly the same working hours, it can be interesting to evaluate the impact of carpooling in terms of CO_{2eq} savings.

Table 4-23 shows that if:

- 5% of the day and evening shift travelled distance was done carpooling; it would lead to a saving of 13.8 tons of CO_{2eq}.

- 50% of the day and evening shift travelled distance was done carpooling; it would lead to a saving of 138.4 tons of CO_{2eq}.

Table 4-23: Carpooling scenario for day and evening shift workers

% of Total distance travelled by day and evening shift with 1 car instead of 2	Total distance travelled by day and evening shift with 1 car instead of 2 (km)	*Emission (kg/year)*			
		CO_2	CH_4	N_2O	CO_{2eq} saved (kg)
5%	59,480	13,456	1	1	13,847
10%	118,960	26,912	2	2	27,694
20%	237,920	53,824	5	5	55,387
30%	356,879	80,736	7	7	83,081
50%	594,799	134,560	11	12	138,468

We can also see that equivalencies between carpooling, remote work and public transportation use can be done, as seen in Table 4-24.

Table 4-24: Equivalencies between carpooling, public transportation use and number of days of remote work

Carpooling	Public transportation	# of Days of remote work
5%	2.2%	7
10%	4.4%	16
20%	8.8%	31
30%	13.1%	47
50%	22%	78

For example, net savings in emissions due to 10% carpooling is equivalent to having 4.4% of the workforce use public transportation or to having 16 days of remote work allowed for office workers.

Again, these results can be interesting when establishing new global environmental strategies in a company. If a company is easily accessible through public transportation, then efforts should be made in order to promote and encourage its use. However, if a company is not easily accessible, one could think that energy should be spent in making it possible for employees to work from home – if the infrastructure allows it, as it is very unlikely that they would shift from the comfort of their cars to a longer commute via public transportation, or even in carpooling programs among its workforce.

Statistically speaking, only 12% of the CUS's employees live less than 10km away from the CUS, compared to the 60% national average in Canada (Statistics Canada, 2008 a)). In addition, the CUS is not near a subway station nor is it well served by public transportation. These two facts suggest that employees will most likely not change their travel habits by car. In the CUS's case, effort should be made in promoting carpooling and the option of allowing more remote work should be studied further, in terms of impact it would have on the general operations of the company.

4.2.4 Building operations

The total amount of CO_{2eq} emitted by the building in a year is 1,158,802 kg, which represents 19% of the total emissions of the CUS.

One of the scenarios we can look at revolves around the location of the CUS.

Companies do not usually choose a location based solely on how much the energy consumption of their building might pollute or how the energy is produced in a particular location. As mentioned above, Quebec's electricity is hydro-electricity, which is one of the cleanest energy available. For the sake of comparison only, we calculated the emissions of the building based on energy bought in Ontario and Nova Scotia. Emission factors given for the electricity usage in both provinces are higher than in Quebec as found in the literature (see Table 2-11).

If we look at the emissions related to electricity use in Table 4-26, we can see that if the CUS was located in Ontario, its building-related total emissions would have been more than 2.5 times the ones of Quebec. If the CUS was located in Nova Scotia, it would have generated more than 5.5 times more emissions than if located in Quebec.

Table 4-25: Summary of monthly energy consumption and GHG emissions over a period of one year

				Actual	Scenario 1	Scenario 2				
				Quebec	Ontario	Nova Scotia				
		Electricity	Natural gas	Electricity			Natural Gas			
Energy bill		Consumption	Consumption	CO_{2eq}	CO_{2eq}	CO_{2eq}	CO_2	CH_4	N_2O	CO_{2eq}
Year	Month	(kWh)	(Meter cube)	kg	kg	kg	kg	kg	kg	kg
2007	February	407,700	67,187	734	105,187	309,444	**127,051**	**32.9**	**3.3**	128,763
2007	March	419,400	55,873	755	108,205	318,325	**105,656**	**27.4**	**2.7**	107,079
2007	April	369,900	41,428	666	95,434	280,754	**78,340**	**20.3**	**2.0**	79,396
2007	May	377,100	14,799	679	97,292	286,219	**27,985**	**7.3**	**0.7**	28,362
2007	June	360,000	1,765	648	92,880	273,240	**3,338**	**0.9**	**0.1**	3,383
2007	July	373,500	913	672	96,363	283,487	**1,726**	**0.4**	**0.0**	1,750
2007	August	383,400	316	690	98,917	291,001	**598**	**0.2**	**0.0**	606
2007	September	358,200	880	645	92,416	271,874	**1,664**	**0.4**	**0.0**	1,687
2007	October	358,200	12,788	645	92,416	271,874	**24,182**	**6.3**	**0.6**	24,508
2007	November	398,700	49,900	718	102,865	302,613	**94,361**	**24.5**	**2.4**	95,632
2007	December	377,100	75,259	679	97,292	286,219	**142,315**	**36.9**	**3.7**	144,232
2008	January	415,800	76,221	748	107,276	315,592	**144,134**	**37.3**	**3.7**	146,076
	Total	**4,599,000**	**397,329**	**8,278**	**1,186,542**	**3,490,641**	**751,349**	**194.7**	**19.5**	**761,473**

Table 4-26: Total emissions in kg of CO_{2eq} resulting from electricity consumption

	Quebec	Ontario (scenatio1)	Nova Scotia (scenario 2)
	Total emissions		
	CO2 eq	CO2 eq	CO2 eq
Month	kg	kg	kg
February	129,496	233,949	438,207
March	107,834	215,285	425,404
April	80,062	174,830	360,150
May	29,041	125,654	314,581
June	4,031	96,263	276,623
July	2,422	98,113	285,236
August	1,296	99,523	291,606
September	2,331	94,102	273,560
October	25,153	116,924	296,382
November	96,350	198,497	398,246
December	144,911	241,524	430,451
January	146,824	253,352	461,668
Total - one year	**769,751**	**1,948,015**	**4,252,114**

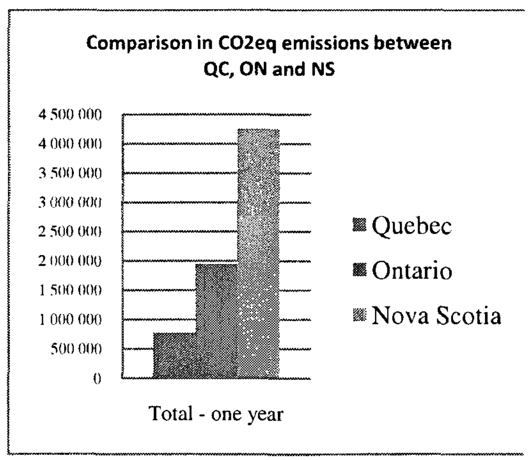

Figure 4-22: Comparison of CO_{2eq} emissions between the three provinces

This comparative study suggests that a company that is in the process of establishing itself somewhere should evaluate how different energy providers have different pollutant effect as part of their environmental studies. Quebec has the advantage to have cleaner energy than most provinces; however, heating needs can be much higher due to colder weather.

A firm of engineering consultant made an energy diagnostic of the building and identified three main projects to reduce energy consumption and therefore emissions. They included the optimization of the ventilation, the lighting as well as the insulation of the building. The estimated savings are listed in Table 4-27.

Table 4-27: Energy saving projects proposed by an energy consultant firm

	Reduction in use		Reduction in GHG (kg)		
	Electricity	Natural Gas	Electricity	Natural Gas	
	(Kwh)	(m3)	CO_{2eq} (kg)	CO_{2eq}	Total Reduction in CO_{2eq} (kg)
Optimization of ventilation	598,000	238,000	1,076	456,122	457,199
Optimization of lighting in warehouse	1,031,000	-33,000	1,856	-63,244	-61,388
Improving insulation of the building	0	12,000	0	22,998	22,998
Total	**1,629,000**	**217,000**	**2,932**	**415,876**	**418,808**

It is to be noted that the lighting project consists in changing the lights and fixture for the entire warehouse: High Pressure Sodium lights would be replaced by the more efficient fluorescent T5H0 lights. The increase shown in the use of natural gas reflects the loss of the heat generated by the High Pressure Sodium lighting. This loss is to be compensated by more heating, hence more natural gas consumed.

Implementing all those projects requires important investments (in the range of 300,000$) but they were evaluated for a return on investment of about 2 years.

Before this paper was over, the lighting project was launched: the CUS obtained a 30% decrease in electricity consumption, but as expected, heating consumptions increased by about 10-15% in the winter months due to the loss of the heat from previous lighting fixtures. The ventilation optimization project is planned for late 2009.

CHAPTER 5 : DISCUSSION

5.1 Overview of the global results

The results presented in the previous section allowed the validation of some of the original assumptions as well as the identification of potential concrete actions that can be undergone to improve the environmental performance of the CUS.

Table 5-1 shows a sample of the different scenarios simulated. Shipping from the US instead of France is showing great saving potential in emissions. The results are presented to show that, theoretically, having closer suppliers results in lower emissions. However, one needs to consider the entire infrastructure of a company: a more thorough analysis needs to be done in order to evaluate the economic feasibility of such project. When benchmarking all the various actions identified previously, it is clear that the most promising one remains the use of rail for shipments in Phase 2 to Alberta and British Columbia, with potential savings in emissions of 1,127.5 tons of CO_{2eq}, compared to the original calculations. Improvements in fill rate lead to less number of vehicles, which leads to additional savings in emissions. However, in the CUS's case, efforts needs to be concentrated on optimizing long distance shipments: a 5% increase in fill rate for shipments in Alberta and British Columbia represent 78.4% of the savings in emissions achieved by increasing fill rate for all shipments.

As for transportation of personnel, having 30% of the worker carpooling leads to an estimated savings of 83.1 tons of CO_{2eq}.It is to be noted that all savings related to the personnel's transportation were compared to the original scenario with 5% of employees using public transportation. Remote work is an avenue that the company could explore if its IT infrastructures as well as its operations allow it. Permitting 30 days a year of remote work per office employee, or about 2.5 days a month, leads to net savings of 51 tons a year. This option could also be beneficial in creating a work environment that is more flexible for the employees.

On the subject of public transportation, even though an increase in its use leads to better environmental results than carpooling, it is unlikely to reach a 20% ratio of employees that would travel through it, simply because of the remote location of the CUS. Finally, projects in energy efficiency are very promising: optimizing the ventilation of the CUS shows the second largest amount of saving, when disregarding the shift in production from France to the US.

Table 5-1: Net saving potentials in tons of CO_{2eq} of the various simulations done

	Potential savings (Tons of CO_{2eq})	Percentage of total emissions
Transportation		
Inbound		
Shipping from the US instead of France	576	9.4%
Outbound		
Increasing fill rate by 5% for Alberta and British Columbia	92.4	1.5%
Increasing fill rate by 5% for all shipments	117.9	1.9%
Using rail for Alberta and British Columbia	1,127.5	18.3%
Personnel		
Having 5% of the night and day shift carpooling	13.8	0.2%
Having 10% of the night and day shift carpooling	27.7	0.5%
Having 20% of the night and day shift carpooling	55.4	0.9%
Having 30% of the night and day shift carpooling	83.1	1.4%
Allowing office workers to 30 days of remote work	51	0.8%
Allowing office workers to 40 days of remote work	68	1.1%
Having 20% of the all employees use public transportation	94	1.5%
Building		
Optimization of ventilation	457.2	7.4%
Improving insulation of the building	23	0.4%

5.2 Recommendations and suggestions for future projects

Outbound transportation

Although all sectors have non-negligible emissions, outbound transportation appeared to be the greatest generator of GHG emissions. It is clear that this is the field to tackle first. We have seen that the greatest savings are obtained when switching transport of good using less environmentally damaging modes – in this instance, rail. Although challenging, the switch should be made first and foremost on shipments for both Alberta and British Columbia. Managers will need to face resistance to change from various departments such as procurement, sales or marketing as this change will require better planning: Rail has longer delays since it does not offer the same door-to-door service as road transport. Although not evaluated in the context of this research, an additional option that should be studied further is the switch to rail for shipments to Ontario: as mentioned by Patterson, Ewing, & Haider (2008), there is great potential in savings in the Quebec-Windsor corridor when using premium-intermodal services offered by CP rail.

On a more operational standpoint, a few ideas rose from the literature review and should be evaluated further. McKinnon (2003) and Jackson (1985) mentioned the aspect of consolidation of orders to reduce the vehicle-km ratio. An avenue that requires further studying is related to the order fulfillment and scheduling of all outbound deliveries. In July 2008, excluding full case picking, 87,705 boxes were prepared in the unit-picking lines. Each shipper was filled by various products that are sold by the unit. Over these 87,705 shippers, 29% had been filled at less than 30% of available volume and 18% had been filled at a ratio between 30 and 50%. This means that almost half of these cases were shipped out half full. When looking at the volume to weight ratio of each of these cases, 65% were below the optimized volume to weight ratio of a 53'ft truck loaded at capacity (3,800ft/29,000pound). In August 2008, the numbers were similar: 81,927 boxes were shipped where 26% were filled at less than 30% and 19% were filled at a ratio between 30 to 50%, with 66% of these cases having a volume to weight ratio inferior to the optimized one. In this paper, we considered the volume and weight of shipments as a whole, but we did not evaluate their content. It is clear that there is an opportunity of better consolidation by readjusting order scheduling so that boxes reach a more optimized volume to weight ratio. For example, a customer that orders three times a week a small quantity of units, should have his orders held in the information system and should be served once a week, in one box, instead of three. In the case of the CUS, the principle of cube utilization should also be applied to orders by the unit. It is clear that there are some disadvantages in implementing more aggressive consolidation methods: the main one being longer order cycle, as mentioned by Jackson (1995). However, negotiation should be done with clients encouraging them to consolidate their orders before sending them to the CUS. An analysis in the frequency of deliveries and their content should be undertaken so that the CUS can determine the principle clients to negotiate with. This requires a review of the entire operational processes, and involves parties from the entire supply chain. In addition, systems such as the *Nominated Day Delivery System* mentioned by McKinnon (2000) can help in the consolidation efforts: in vast geographical areas such as Canada, consolidating orders by region can help reduce traffic levels and therefore emissions. If rail cannot be implemented throughout, this alternative should be further studied.

All transport activity is subcontracted by the CUS. Therefore, auditing them would be a good practice. When establishing strong partnerships, it is important to align every party involved with the same environmental strategies. Some aspects in environmental performance are not under the CUS's control. For example, the CUS should partner with transporters that follow good maintenance procedures of their fleet, use wide based tires or even offer driving classes to their drivers, as these are more subtle characteristics that would lead to environmental excellence (EPA, 2004; Nix, 2003; Rafael-Morales & Cervantes-de Gortar, 2002). It is very difficult to evaluate the potential savings in emissions of these good practices; however, research shows that some of them could reduce fuel use by up to 20%. Another aspect to consider is the mix of clients the transporter deals with. Volume and weight of deliveries vary from client to client. In order to optimize cube utilization, transporters must try to combine clients with products of various density and volume. The change in nature of products is an aspect that was mentioned by McKinnon (2000) and it is a reality transporters need to be working with. The use of double deck trailers can help with cube optimization, especially when dealing with products or pallets of various shape and density (McKinnon & Campbell, 1997). Finally, the use of route planning software is becoming a must when dealing with objectives to reduce emissions (Greater Vancouver Regional District, 2007)

Inbound transportation

Reducing the impact of inbound transportation requires more effort from even more parties than in the case of outbound transportation. The same principles apply when it comes to consolidation of orders; however these need to be applied by the suppliers with the help of the CUS's procurement team. Procurement is based on forecasted sales and this is unfortunately not an exact science. Just in time pressures tend to lead to a lesser degree of load consolidations (McKinnon A. C., 2000). Objectives to reduce safety stock levels also come in the equation. The choices of suppliers as well as the infrastructure of the global operations are some of the factors that cannot be changed once in place (McKinnon A. C., 2003). It is therefore very difficult to reduce the impact of inbound transport since most of it is not under the direct control of the CUS. Efforts should be put in priority in the other sectors of the CUS. Avoiding rushed air shipments is one of the only recommendations that can be made on a short term basis, as it is even more environmentally damaging than road and sea transport.

Personnel transportation

With 16% of emissions originating from transportation of personnel, it is clear that this sector cannot be neglected. Carpooling programs should be implanted in priority. Incentives should be offered to employees to promote the project: it is a solution that requires some energy, but not a lot of investments. As previously mentioned, there is no monetary gain in implementing such program, however the company's image will be improved and will reflect its environmental position. Promoting public transportation could be done, but it is not likely to succeed due to the remote location of the site. Another option that could be taken is offer monthly incentives to encourage the people that do take it. Informative campaigns could also be done to encourage people to adopt more environmentally friendly travel habits, or even to help them choose more efficient cars.

Building operations

We have seen that there is a great potential in emission savings when it comes to the operations of the building. Although not certified LEED, the building was built about 9 years ago, where technology might not have been as advanced when it comes to energy efficiency. Projects such as the lighting projects showed a great decrease in energy use, which translated in dollar saving. The next step is the implementation of the ventilation project, which will allow even greater savings in emissions and also, in dollars. This project should be a priority, as it is easy to implement, is economically viable, and leads to great environmental results.

Finally, one last aspect that was not taken into consideration was the impact of all the waste generated by the CUS. This can also be part of future developments.

CHAPTER 6 : CONCLUSION

The protection of the environment is at the heart of today's global issues. Businesses across the world are facing new challenges and are required, through social or political pressures, to become more sustainable. However, there is a lack of information when it comes to the comparative environmental impact of a company's internal operations. This problem was the core of this research paper. In order to help management committees develop sound environmental strategies, the evaluation of GHG emissions was done on an existing logistic platform. The emissions of the following sectors were calculated: the transportation of goods (inbound and outbound), the transportation of personnel and the building's operations.

The literature review allowed us to identify the elements needed to do such calculation and helped us identify concrete actions that would lead to savings in emissions. The results obtained showed that transportation of goods was the biggest GHG generator with 37.4% of total emissions allocated to outbound transportation and 28% to inbound transportation, followed by the building's operations with 18.8% of total emissions and the transportation of personnel with 15.7% of total emissions.

Various scenarios were then developed in order to evaluate the validity of the assumptions made and also to estimate the potential savings that could be obtained by varying them. The most promising results were found when rail transportation was used for shipments to Alberta and British Columbia instead of road transportation. Other actions were identified such as the promotion of carpooling among employees, the establishment of a remote work policy and the implementation of energy efficiency projects such as the centralization and optimization of the ventilation system.

Finally, further developments were suggested in order to reach even better environmental results: a thorough analysis should be done on the frequency of deliveries in parallel with the space utilization of boxes. There is great potential for increasing consolidation in orders by implementing more transport-efficient order cycles.

BIBLIOGRAPHY

Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME). (2007). *Bilan Carbone d'Entreprises et Collectivités - Guide des facteurs d'emissions version 5*. Paris: ADEME.

Aker, J. M. (2008). The Qualities of Great Distribution Centres. *Industrial Facilities* , pp. 54-56.

Ang, B. W., & Zhang, F. Q. (2000). A survey of index decomposition analysis in energy and environmental studies. *Energy* , 1149–1176.

Atkyns, R., Blazek, M., Roitz, J., & AT&T. (2002). Measurement of environmental impacts of telework adoption amidst change in complex organizations: AT&T survey methodology and results. *Resources, Conservation and Recycling , 36*, 267-285.

Brundtland, G. H. (1987). Our Common Future. *World Commission on Environment and Development* (p. 89). Oxford University Press.

CBORD Inc. (2008). *CBORD's Efforts to Lessen its Environmental Impact.* Retrieved September 30, 2008, from The CBORD Group, Inc.: http://hcl.cbord.com/about/green/

Centres for Disease Control and Prevention. (2000). Corporate Action to Reduce Air Pollution -- Atlanta, Georgia, 1998-1999. *Morbid and Mortality Weekly Report* , pp. 153-156.

Clift, R. (1998). Engineering for the Environment The New Model Engineer and her Role. *Process Safety and Environmental Protection , 76* (2), 151-160.

CNW Marketing Research Inc. (2007). *Dust to dust.* Retrieved September 25, 2008, from CNW Research: http://cnwmr.com/nss-folder/automotiveenergy/

Comité de Gestion Environnementale de Polytechnique. (2008). *Rapport sur l'environnement 2006-2007.* Retrieved 09 19, 2008, from Ecole Polytechnique de Montréal: http://www.polymtl.ca/enviropoly/docs/documents/Rapport_environnement_2006_2007.pdf

Conseil du bâtiment durable du Canada. (2007). *LEED green building rating system : guide de référence LEED Canada - CI pour l'aménagement intérieur des espaces commerciaux.* Ottawa: Conseil du bâtiment durable du Canada.

Danielis, R., & Marcucci, E. (2007). Attribute cut-offs in freight service selection. *Transportation Research Part E* , 506–515.

De Haan, P., Peters, A., & Scholz, R. W. (2007). Reducing energy consumption in road transport through hybrid vehicles: investigation of rebound effects, and possible effects of tax rebates. *Journal of Cleaner Production* , 1076-1084.

DiBenedetto, B. (2008). Distribution centres go green. *The journal of commerce* , pp. 27-28.

Dimitris, P., & Kanaroglou, P. S. (2007). Household demand and willingness to pay for clean vehicles. *Transportation Research Part D* , 264–274.

Environment Canada. (2003). *Science of Climate Change.* Retrieved May 20, 2008, from Environment Canada: http://www.msc-smc.ec.gc.ca/education/scienceofclimatechange/understanding/greenhouse_gases/index_e.html

Environment Canada. (2004). *Canada's Greenhouse Gas Inventory, 1990–2002.* Retrieved March 29, 2009, from Environment Canada Web site: http://www.ec.gc.ca/pdb/ghg/inventory_report/1990_02_report/toc_e.cfm

Environment Canada. (2005). *CEPA Envrionmental Registry - GHG Notice of Objection.* Retrieved March 29, 2008, from Environment Canada Web site: http://www.ec.gc.ca/CEPARegistry/documents/part/LFE_drft_inst/LFE_drft_inst.cfm

Environment Canada. (2006). *About the Kyoto Protocol.* Retrieved April 25, 2008, from Environment Canada: http://www.ec.gc.ca/pdb/ghg/about/kyoto_e.cfm

Environment Canada. (2007 a)). *Action on Industrial Greenhouse Gas Emissions.* Retrieved June 15, 2008, from Environment Canada: http://www.ec.gc.ca/default.asp?lang=En&xml=D318C75B-0034-45EF-937E-D3607773C0D2

Environment Canada. (2007 b)). *National Inventory Report, 1990-2005 - Greenhouse Gas Sources and Sinks in Canada.* Retrieved June 2008, from Environment Canada: http://www.ec.gc.ca/pdb/ghg/inventory_report/2005_report/s3_2_eng.cfm

Environment Canada. (2008 a)). *Clear Air Online - Transportation Related Activities.* Retrieved October 02, 2008, from Environnemnt Canada Web site: http://www.ec.gc.ca/cleanair-airpur/default.asp?lang=En&xml=2D89E784-59BE-49EF-9725-219A67B573F8

Environment Canada. (2008 b)). *National Inventory Report 1990-2006: Greenhouse Gas Sources and Sinks in Canada.* Retrieved March 28, 2009, from Environment Canada: http://www.ec.gc.ca/pdb/ghg/inventory_report/2006_report/2006_report_e.pdf

EPA. (2004). *EPA Technical Bulletins: A Glance at Clean Freight Strategies.* Retrieved October 18, 2008, from The EPA Website: http://www.epa.gov/smartway/transport/partner-resources/resources-publications.htm

EPA. (2007). *Climate Change - What You Can Do - At the Office.* Retrieved October 02, 2008, from Environmental Protection Agency US: http://www.epa.gov/climatechange/wycd/office.html

EPA. (2008). *Climate Leaders - Technical Resources.* Retrieved March 28, 2009, from The EPA Website: http://www.epa.gov/climateleaders/resources/index.html

EPA. (2009). *Optional Emissions from Commuting, Business travel and Product transport.* Retrieved March 28, 2009, from EPA website: http://www.epa.gov/climateleaders/resources/

Ewing, G. O., & Sarigöllü, E. (1998). Car fuel-type choice under travel demand management and economic incentives. *Transportation Research Part D: Transport and Environment , Volume 3* (Issue 6), 429-444.

Fontarasa, G., Pistikopoulosa, P., & Samaras, Z. (2008). Experimental evaluation of hybrid vehicle fuel economy and pollutant emissions over real-world simulation driving cycles. *Atmospheric Environment , Volume 42* (Issue 18), 4023-4035.

Governement of Canada. (2008 a)). *ecoACTION, Using less - Living better.* Retrieved September 25, 2008, from Government of Canada: http://www.ecoaction.gc.ca/initiatives/consumers-consommateurs-eng.cfm

Government of Canada. (2008 b)). *GHG reporting site.* Retrieved May 20, 2008, from Government of Canada: http://www.ghgreporting.gc.ca/GHGInfo/Pages/page13.aspx

Greater Vancouver Regional District. (2007). *Sustainable Supply Chain Logistics Guide.* Retrieved October 10, 2008, from Metro Vancouver: http://www.metrovancouver.org/about/publications/Publications/sustainablesclgu idefinal.pdf

Hewlett-Packard Inc. (2008). *HP Environment: Telecommuting and Employee Travel.* Retrieved October 02, 2008, from Hewlett-Packard Development Company: http://www.hp.com/hpinfo/globalcitizenship/environment/operations/travel.html

Holzapfel, H. (1995). Potential forms of regional economic co-operation to reduce goods transport. *World Transport Policy and Practice* , *1* (2), 34-39.

Hybrid Cars Inc. (2008). *August 2008 Dashboard: Undersupply and Discouraged Buyers*. Retrieved September 27, 2008, from Hybrid Cars: http://www.hybridcars.com/market-dashboard/august-2008-dashboard-undersupply-and-discouraged-buyers-24953.html

Intergovernmental Panel on Climate Change (IPCC). (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Retrieved September 21, 2008, from Intergovernmental Panel on Climate Change - National Greenhouse Gas Inventories Programme: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Jackson, J. (1985). A survey of freight consolidation practices. *Journal of Business Logistics* , *6* (1), 13-34.

Logistics & Transport Focus. (2003). Government-Backed Survey To Cut Retail Supply-Chain Waste. *Logistics & Transport Focus* , *5* (10), p. 8.

Matthiessen, L. F., & Morris, P. (2007). *Cost of Green Revisited: Reexamining the Feasibility and Cost Impact of Sustainable Design in the Light of Increased Market Adoption.* Retrieved October 05, 2008, from Davis Langdon Corporation Web site: http://www.davislangdon.com

McKinnon, A. C. (1998). Logistical restructuring, road freight traffic growth and the environment. In D. Banister, *Transport policy and the environment* (pp. 97-112). London: Spon.

McKinnon, A. C. (2000). Sustainable distribution: opportunities to improve vehicle loading. *Industry and Environment* , *23*, 26-30.

McKinnon, A. C. (2003). Logistics and the environment. In D. A. Hensher, & K. J. Button, *Handbook of transport and the environment* (pp. 665-685). Oxford: Elsevier Ltd.

McKinnon, A. C. (2005). The economic and environmental benefits of increasing maximum truck weight: the British experience. *Transportation Research Part D: Transport and Environment*, *10* (1), 77-95.

McKinnon, A. C., & Campbell, J. (1997). *Opportunities for Consolidating Volume-constrained Loads in Double-Deck and High-Cube Vehicles.* Edinburgh: Heriot-Watt University.

McKinnon, A. C., Ge, Y., & Leuchars, D. (2003). *Key Performance Indicators for the Food Supply Chain.* Freight Best Practice. Queens: Departement of Transport.

Morgan Cole Inc. (2008). *Environmental Policy.* Retrieved September 29, 2008, from Morgan Cole Web site: http://www.morgan-cole.com/aboutus/environmentalpolicy.html

Morris, P. (2007). *What Does Green Really Cost?* Retrieved March 14, 2009, from The US Green Building Council: http://www.usgbc.org

National Renewable Energy Laboratory (NREL). (2008). *Sustainable NREL.* Retrieved October 02, 2008, from National Renewable Energy Laboratory: http://www.nrel.gov/sustainable_nrel/

Natural Resources of Canada. (2007). *Transportation GHG Emissions by Energy Source and Transportation Mode.* Retrieved June 22, 2008, from Natural Resources of Canada: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tableshandbook2/tran_00_2_e_2.cfm?attr=0

Nix, F. P. (2003). *Truck Activity in Canada - A Profile.* Ottawa: Transport Canada.

OEE. (2001). *Fuel Efficiency Benchmarking in Canada's Trucking Industry.* Ottawa: Natural Resources Canada.

OEE. (2006). *The State of Energy Efficiency in Canada, Office of Energy Efficiency Report 2006.* Ottawa: Natural Resources Canada.

OEE. (2007 a)). *Energy Use Data Handbook Tables (Canada).* Retrieved October 03, 2008, from Office of Energy Efficiency: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook_tables.cfm?attr=0

OEE. (2007 b)). *Commercial and Institutional Consumption of Energy Survey, Summary Report – June 2007.* Ottawa: National Resources Canada.

OEE. (2007 c)). *Energy Efficiency Trends Analysis Tables (Canada).* Retrieved October 02, 2008, from Natural Resources Canada: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablesanalysis2/com_00_1_e_1_2.cfm?attr=0

OEE. (2007 d)). *Transportation GHG Emissions by Energy Source and Transportation Mode.* Retrieved June 30, 2008, from Natural Resources of Canada: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tableshandbook2/tran_00_2_e_2.cfm?attr=0

OEE. (2008). *Office of Energy Efficiency (OEE).* Retrieved May 25, 2008, from Natural Resources Canada: http://oee.nrcan.gc.ca/publications/infosource/home/index.cfm?act=category&PrintView=N&Text=N

Patterson, Z., Ewing, G. O., & Haider, M. (2008). The potential for premium-intermodal services to reduce freight CO2 emissions in the Quebec City–Windsor Corridor. *Transportation Research Part D: Transport and Environment*, *13* (1), 1-9.

Pendrous, R. (2008). Greening of distribution warehouses is set to take off. *Food Manufacture* , p. 22.

Putt del Pino, S., Levinson, R., & Larsen, J. (2006). *Hot Climate, Cool Commerce: A Service Sector Guide to Greenhouse Gas Management.* Washington: World Resources Institute.

Rafael-Morales, M., & Cervantes-de Gortar, J. (2002). Reduced consumption and environment pollution in Mexico by optimal technical driving of heavy motor vehicles. *Energy* , 1131–1137.

Ramanathan, R. (2000). A holistic approach to compare energy efficiencies of different transport modes. *Energy Policy* , *28* (11), 743-747.

Romm, J. (2006). The car and fuel of the future. *Energy Policy* , 2609–2614.

Rose, G., & Ampt, E. (2003). Travel behavior change through individual engagement. In D. A. Hensher, & K. J. Button, *Handbook of transport and the Environment* (pp. 739-755). Oxford: Elsevier Ltd.

Samuelsson, A., & Tilanus, B. (1997). A framework efficiency model for goods transportation, with an application to regional less-than-truckload distribution. *Transport Logistics* , *1*, 85-152.

Statistics Canada. (2008 a)). *Commuting Patterns and Places of Work of Canadians, 2006 Census.* Ottawa: Statistics Canada.

Statistics Canada. (2008 b)). *2006 Census: Data and product.* Retrieved October 03, 2008, from Statistics Canada Web site: http://www12.statcan.ca/english/census06/data/index.cfm

Statistics Canada. (2008 c)). *Statistic Canada, Human Activity and the Environment: Annual Statistics 2007 and 2008.* Retrieved May 20, 2008, from Statistics Canada: http://www.statcan.ca/english/freepub/16-201-XIE/16-201-XIE2007000.pdf

Steenhof, P., Woudsma, C., & Sparling, E. (2006). Greenhouse gas emissions and the surface transport of freight in Canada. *Transportation Research Part D: Transport and Environment* , *11* (5), 369-376.

Sun Microsystems Inc. (2008). *Environment, Health and Safety - Commuting and Commute Alternatives.* Retrieved October 02, 2008, from Sun Microsystems Corporation Web site: http://www.sun.com/aboutsun/ehs/ehs-commute.html

Sustainable Silicon Valley. (2008). *Sustainable Silicon Valley - Tools & Resources.* Retrieved October 02, 2008, from Sustainable Silicon Valley Web site: http://www.sustainablesiliconvalley.org/

The GHG Protocol. (2003). *A Corporate Accounting and Reporting Standard.* Retrieved October 10, 2008, from The GHG Protocol: http://www.ghgprotocol.org/files/ghg-protocol-revised.pdf

The GHG Protocol. (2006). *The GHG Protocol - Service Sector.* Retrieved October 02, 2008, from The GHG Protocol Initiative: http://www.ghgprotocol.org/calculation-tools/service-sector

The GHG Protocol. (2009). *Calculation tools.* Retrieved March 28, 2009, from The GHG Protocol Initiative: http://www.ghgprotocol.org/calculation-tools/all-tools

Transport Canada. (2004). *Sustainable Development Strategy, 2004-2006.* Ottawa: Ministry of Transport.

Transport Canada. (2007). *Transportation in Canada: An Overview.* Retrieved June 22, 2008, from Transport Canada: http://www.tc.gc.ca/policy/Report/anre2007/pdf/overview.pdf

UK Departement for Transport. (2005). *Computerised Vehicle Routing and Scheduling (CVRS) for Efficient Logistics.* Retrieved October 19, 2008, from Freight Best Practice Web site: http://www.freightbestpractice.org.uk

United Nation Economic Commission for Europe (UNECE). (2006). *Passenger Vehicles (number) at 31 December by Vehicle Category, Country and Year.* Retrieved September 29, 2008, from United Nation Economic Commission for Europe: http://w3.unece.org/pxweb/Dialog/Saveshow.asp

Witt, C. E. (2007). It's easy being green. *Logistics Today* , pp. 38-42.

WRI. (2008). *World Resources Institute: Innovations in estimating employee commuting emissions.* Retrieved October 02, 2008, from World Resources Institute: http://www.wri.org/publication/content/8692

Yoders, J. (2006). A worker's paradise. *Building Design & Construction* , pp. 33-36.

APPENDICES

APPENDIX A: Sample of detailed calculation of CO_{2eq} emissions from employees commuting

	Two way	*Per year*	Kg per day (2-way commute)			KG per day	KG per year
Shit	**Distance (km)**	**Distance (km)**	**CO_2 emission**	**CH_4 Emission**	**N_2O Emission**	**$CO_{2eq.}$**	**$CO_{2eq.}$**
Day	56	13,779	13	0	0	13	3,208
Day	46	11,353	10	0	0	11	2,643
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
Day	71	17,410	16	0	0	17	4,053
Day	122	29,924	28	0	0	28	6,966
Day	112	27,509	25	0	0	26	6,404
Day Total		**1,471,999**				**1,399**	**342,678**
Evening	43	10,613	10	0	0	10	2,471
Evening	73	17,939	17	0	0	17	4,176
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
Evening	10	2,362	2	0	0	2	550
Evening	54	13,142	12	0	0	12	3,059
Evening	30	7,247	7	0	0	7	1,687
Evening Total		**907,196**				**862**	**211,193**
Office	53	13,054	12	0	0	12	3,039
Office	55	13,455	12	0	0	13	3,132
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
Office	21	5,125	5	0	0	5	1,193
Office	63	15,509	14	0	0	15	3,610
Office	16	3,832	4	0	0	4	892
Office Total		**1,865,866**				**1,773**	**434,369**
Visitors	150	36,750	34	0	0	35	8,555
Visitors Total		**36,750**				**35**	**8,555**
Grand Total		**4,281,811**				**4,069**	**996,794**

APPENDIX B: Sample of spreadsheet used for the calculation of emissions on Phase 2 and 3

Type de client	City	Region	Distance	Yearly weight (kg)	Yearly volume (ccm)	Volume to weight ratio (ccm/kg)	Number of 53'	Number of 24'	Emissions on Phase 2	Emissions on Phase 3	Emissions due to detour (d4)	Total Emission in CO_{2eq} (EXCLUDING Phase 1)
Distributor	AIRDRIE	AB	4,029	123,000	1.07E+09	8,629	14	35	22,511	0	0	22,511
Distributor	MISSISSAUGA	ON	554	121,000	8.18E+08	6,767	13	27	2,872	0	0	2,872
Distributor	OTTAWA	ON	172	106,000	4.34E+08	4,093	12	21	782	0	0	782
Distributor	DARTMOUTH	NS	1,210	100,000	5.19E+08	5,190	11	20	5,188	0	0	5,188
Distributor	LAVAL	QC	17	95,200	3.71E+08	3,893	10	19	68	0	0	68
Distributor	CALGARY	AB	4,017	87,300	5.73E+08	6,557	10	19	15,037	0	0	15,037
Distributor	RICHMOND	BC	4,812	83,100	1.89E+08	2,276	9	16	17,132	0	0	17,132
Regular Client	MARKHAM	ON	522	82,600	4.02E+08	4,868	9	16	1,664	231	9	1,904
Distributor	NEUFCHATEL	QC	268	81,000	4.48E+08	5,536	9	16	932	0	0	932
Regular Client	MONTREAL	QC	20	76,700	3.54E+08	4,610	8	15	61	8	8	77
Distributor	CALGARY	AB	4,004	76,300	3.17E+08	4,158	8	15	13,095	0	0	13,095
Distributor	ETOBICOKE	ON	546	74,700	5.20E+08	6,958	8	17	1,747	0	0	1,747
Regular Client	MONTREAL	QC	20	69,800	3.86E+08	5,533	8	14	55	8	7	70
Distributor	ST. JOHN'S	NF	2,249	65,200	4.48E+08	6,882	7	15	6,282	0	0	6,282
Distributor	CALGARY	AB	4,000	57,100	1.92E+08	3,356	6	11	9,787	0	0	9,787
Regular Client	MONTREAL	QC	20	54,000	2.41E+08	4,459	6	11	43	6	6	54
Distributor	MONTREAL-NORD	QC	27	50,400	1.18E+08	2,350	6	10	58	0	0	58
Distributor	VANCOUVER	BC	4,821	48,000	3.19E+08	6,636	5	10	9,927	0	0	9,927
Distributor	CALGARY	AB	4,008	45,300	2.18E+08	4,811	5	9	7,780	0	0	7,780
Distributor	EDMONTON	AB	3,998	42,200	1.10E+08	2,607	5	8	7,231	0	0	7,231
Regular Client	MONTREAL	QC	20	41,700	2.91E+08	6,992	5	9	33	5	5	43
Regular Client	OTTAWA	ON	171	40,800	2.54E+08	6,208	4	8	270	39	4	313

Type de client	City	Region	Distance	**Yearly weight (kg)**	Yearly volume (ccm)	Volume to weight ratio (ccm/kg)	Number of 53'	Number of 24'	Emissions on Phase 2	Emissions on Phase 3	Emissions due to detour (d4)	Total Emission in CO_{2eq} **(EXCLUDING** Phase 1)
Distributor	RIVIERE DU LOUP	QC	447	39,900	1.32E+08	3,294	4	8	765	0	0	765
Distributor	CONCORD	ON	536	32,300	1.09E+08	3,366	4	6	742	0	0	742
Major Client	HAMILTON	ON	597	32,000	1.79E+07	560	4	6	738	103	0	841
Regular Client	MONTREAL	QC	20	31,200	1.49E+08	4,768	3	6	25	3	3	31
Distributor	DUBERGER	QC	266	30,600	7.33E+07	2,393	3	6	349	0	0	349
Major Client	SCARBOROUGH	ON	512	30,000	1.34E+08	4,461	3	6	593	82	0	675
Distributor	HALIFAX	NS	1,222	29,400	1.05E+08	3,554	3	6	1,542	0	0	1,542
Regular Client	ETOBICOKE	ON	544	29,100	8.46E+07	2,904	3	6	611	85	3	699
Distributor	WINNIPEG	MB	2,749	27,900	1.31E+08	4,711	3	5	3,288	0	0	3,288
Distributor	COQUITLAM	BC	4,804	27,700	1.12E+08	4,026	3	5	5,708	0	0	5,708
Major Client	SUDBURY	ON	660	26,100	1.20E+08	4,597	3	5	666	92	0	759
Major Client	CONCORD	ON	539	25,600	1.17E+08	4,550	3	5	533	74	0	607
Major Client	TORONTO	ON	533	24,800	1.19E+08	4,803	3	5	510	71	0	580
Regular Client	VANIER	QC	269	24,700	2.67E+08	10,796	4	9	338	64	5	407
Major Client	BRAMPTON	ON	560	24,400	1.28E+08	5,220	3	5	528	73	0	602
Regular Client	EDMONTON	AB	3,998	23,700	1.54E+08	6,492	3	5	3,655	545	3	4,203
Regular Client	OAKVILLE	ON	560	23,700	1.98E+08	8,350	3	6	522	98	4	624
Major Client	CALGARY	AB	4,002	23,500	1.07E+08	4,568	3	5	3,631	504	0	4,135
Major Client	ST-LEONARD	QC	22	23,400	1.10E+08	4,692	3	5	20	3	0	22
Major Client	BRAMPTON	ON	549	23,100	1.08E+08	4,672	3	5	489	68	0	557
Distributor	ST. JOHN'S	NF	2,246	22,400	1.02E+08	4,562	2	4	2,156	0	0	2,156
Major Client	RIV-DES-PRAIRIES	QC	33	21,800	7.02E+07	3,221	2	4	28	4	0	32

APPENDIX C: Results obtained by varying d_1 and fill rate on Phase 1

Fill rate	Number of equivalent 53' trucks	CO_{2eq} emissions (kg) with **d1=10km**	CO_{2eq} emissions (kg) with **d1=5km**	CO_{2eq} emissions (kg) with **d1=15km**
10%	63280	**250,019**	**125,010**	**375,029**
20%	31640	**125,010**	**62,505**	**187,514**
30%	21093	**83,340**	**41,670**	**125,010**
40%	15820	**62,505**	**31,252**	**93,757**
50%	12656	**50,004**	**25,002**	**75,006**
55%	11505	**45,458**	**22,729**	**68,187**
60%	10547	**41,670**	**20,835**	**62,505**
65%	9735	**38,465**	**19,232**	**57,697**
70%	9040	**35,717**	**17,859**	**53,576**
71%	8913	**35,214**	**17,607**	**52,821**
72.%	8789	**34,725**	**17,362**	**52,087**
73%	8668	**34,249**	**17,125**	**51,374**
74 %	8551	**33,786**	**16,893**	**50,680**
75%	8437	**33,336**	**16,668**	**50,004**
76%	8326	**32,897**	**16,449**	**49,346**
77%	8218	**32,470**	**16,235**	**48,705**
78%	8113	**32,054**	**16,027**	**48,081**
79%	8010	**31,648**	**15,824**	**47,472**
80%	7910	**31,252**	**15,626**	**46,879**
85%	7445	**29,414**	**14,707**	**44,121**
90 %	7031	**27,780**	**13,890**	**41,670**
95%	6661	**26,318**	**13,159**	**39,477**
100 %	6328	**25,002**	**12,501**	**37,503**

APPENDIX D: Detailed results obtained with varying fill rate on all phases

Fill rate	Emissions Phase 1	Emissions Phase 2	Emissions Phase 3	Emissions detour (d_4=2km)	Total Emissions in CO_{2eq}	% of total from: Phase 1	Phase 2	Phase 3	detour
10	250,019	12,287,441	374,121	1,698	**12,913,280**	1.94%	95.15%	2.90%	0.01%
20	125,010	6,402,875	194,984	885	**6,723,754**	1.86%	95.23%	2.90%	0.01%
30	83,340	4,441,353	135,272	614	**4,660,579**	1.79%	95.30%	2.90%	0.01%
40	62,505	3,460,592	105,415	479	**3,628,991**	1.72%	95.36%	2.90%	0.01%
50	50,004	2,872,136	87,502	397	**3,010,038**	1.66%	95.42%	2.91%	0.01%
55	45,458	2,658,151	80,988	368	**2,784,965**	1.63%	95.45%	2.91%	0.01%
60	41,670	2,479,831	75,559	343	**2,597,403**	1.60%	95.47%	2.91%	0.01%
65	38,465	2,328,945	70,966	322	**2,438,698**	1.58%	95.50%	2.91%	0.01%
70	35,717	2,199,614	67,029	304	**2,302,664**	1.55%	95.52%	2.91%	0.01%
71	35,214	2,175,934	66,308	301	**2,277,756**	1.55%	95.53%	2.91%	0.01%
72	34,725	2,152,911	65,607	298	**2,253,541**	1.54%	95.53%	2.91%	0.01%
73	34,249	2,130,519	64,925	295	**2,229,989**	1.54%	95.54%	2.91%	0.01%
74	33,786	2,108,733	64,262	292	**2,207,073**	1.53%	95.54%	2.91%	0.01%
75	33,336	2,087,527	63,617	289	**2,184,768**	1.53%	95.55%	2.91%	0.01%
76	32,897	2,066,879	62,988	286	**2,163,051**	1.52%	95.55%	2.91%	0.01%
77	32,470	2,046,768	62,376	283	**2,141,897**	1.52%	95.56%	2.91%	0.01%
78	32,054	2,027,172	61,779	280	**2,121,286**	1.51%	95.56%	2.91%	0.01%
79	31,648	2,008,073	61,198	278	**2,101,197**	1.51%	95.57%	2.91%	0.01%
80	31,252	1,989,451	60,631	275	**2,081,610**	1.50%	95.57%	2.91%	0.01%
85	29,414	1,902,913	57,997	263	**1,990,587**	1.48%	95.60%	2.91%	0.01%
90	27,780	1,825,991	55,655	253	**1,909,678**	1.45%	95.62%	2.91%	0.01%
95	26,318	1,757,165	53,560	243	**1,837,286**	1.43%	95.64%	2.92%	0.01%
100	25,002	1,695,223	51,674	235	**1,772,133**	1.41%	95.66%	2.92%	0.01%

APPENDIX E: Number of trucks by Phase, by Province, with varying fill rate

	Alberta			Manitoba			British Columbia			Ontario			Saskatoon		
Fill rate	Total emission (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emission (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emission (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emission (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emission (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3
10	5,401,153	4,246	8,415	171,534	188	365	4,727,325	3,098	6,598	1,481,548	9,587	19,426	5,401,153	4,246	8,415
20	2,814,502	2,123	4,207	89,386	94	183	2,463,377	1,549	3,299	772,027	4,794	9,713	2,814,502	2,123	4,207
30	1,952,285	1,415	2,805	62,004	63	122	1,708,727	1,033	2,199	535,520	3,196	6,475	1,952,285	1,415	2,805
40	1,521,177	1,061	2,104	48,313	47	91	1,331,403	775	1,650	417,266	2,397	4,856	1,521,177	1,061	2,104
50	1,262,512	849	1,683	40,098	38	73	1,105,008	620	1,320	346,314	1,917	3,885	1,262,512	849	1,683
55	1,168,452	772	1,530	37,111	34	66	1,022,682	563	1,200	320,513	1,743	3,532	1,168,452	772	1,530
60	1,090,069	708	1,402	34,621	31	61	954,078	516	1,100	299,013	1,598	3,238	1,090,069	708	1,402
65	1,023,744	653	1,295	32,515	29	56	896,028	477	1,015	280,820	1,475	2,989	1,023,744	653	1,295
70	966,895	607	1,202	30,710	27	52	846,271	443	943	265,226	1,370	2,775	966,895	607	1,202
71	956,486	598	1,185	30,379	26	51	837,160	436	929	262,371	1,350	2,736	956,486	598	1,185
72	946,366	590	1,169	30,058	26	51	828,303	430	916	259,595	1,332	2,698	946,366	590	1,169
73	936,523	582	1,153	29,745	26	50	819,688	424	904	256,895	1,313	2,661	936,523	582	1,153
74	926,947	574	1,137	29,441	25	49	811,306	419	892	254,268	1,296	2,625	926,947	574	1,137
75	917,625	566	1,122	29,145	25	49	803,148	413	880	251,711	1,278	2,590	917,625	566	1,122
80	874,514	531	1,052	27,776	24	46	765,415	387	825	239,886	1,198	2,428	874,514	531	1,052
85	836,475	499	990	26,568	22	43	732,122	365	776	229,452	1,128	2,285	836,475	499	990
90	802,663	472	935	25,494	21	41	702,528	344	733	220,177	1,065	2,158	802,663	472	935
95	772,410	447	886	24,533	20	38	676,049	326	695	211,878	1,009	2,045	772,410	447	886
100	745,182	425	841	23,668	19	37	652,218	310	660	204,410	959	1,943	745,182	425	841

	North Territories			Nunavut			Prince Edward Ilands			Yukon		
Fill rate	Total emission (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emission (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emission (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emission (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3
10	11,482	6	6	14	0	0	4,623	13	26	10,378	5	11
20	5,983	3	3	7	0	0	2,409	6	13	5,408	3	5
30	4,150	2	2	5	0	0	1,671	4	9	3,751	2	4
40	3,234	2	2	4	0	0	1,302	3	6	2,923	1	3
50	2,684	1	1	3	0	0	1,081	3	5	2,426	1	2
55	2,484	1	1	3	0	0	1,000	2	5	2,245	1	2
60	2,318	1	1	3	0	0	933	2	4	2,095	1	2
65	2,177	1	1	3	0	0	876	2	4	1,967	1	2
70	2,056	1	1	2	0	0	828	2	4	1,858	1	2
71	2,034	1	1	2	0	0	819	2	4	1,838	1	2
72	2,012	1	1	2	0	0	810	2	4	1,819	1	1
73	1,991	1	1	2	0	0	802	2	4	1,800	1	1
74	1,971	1	1	2	0	0	794	2	3	1,781	1	1
75	1,951	1	1	2	0	0	786	2	3	1,763	1	1
80	1,859	1	1	2	0	0	749	2	3	1,681	1	1
85	1,778	1	1	2	0	0	716	1	3	1,607	1	1
90	1,707	1	1	2	0	0	687	1	3	1,542	1	1
95	1,642	1	1	2	0	0	661	1	3	1,484	1	1
100	1,584	1	1	2	0	0	638	1	3	1,432	1	1

	Quebec			New Brunswick			Newfoundland			Nova Scotia			CANADA		
Fill rate	Total emissions (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emission (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emission s(kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emissions (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3	Total emissions (kg of CO_{2eq})	Number of 53' trucks on Phase 2	Number of 24' trucks on Phase 3
10	164,176	4,525	9,071	91,811	322	608	112,427	165	321	255,382	664	1,393	12,593,766	22,969	46,527
20	85,552	2,263	4,536	47,842	161	304	58,586	82	161	133,078	332	696	6,562,530	11,485	23,264
30	59,344	1,508	3,024	33,186	107	203	40,638	55	107	92,310	221	464	4,552,118	7,656	15,509
40	46,240	1,131	2,268	25,858	81	152	31,665	41	80	71,926	166	348	3,546,913	5,742	11,632
50	38,377	905	1,814	21,461	64	122	26,280	33	64	59,695	133	279	2,943,789	4,594	9,305
55	35,518	823	1,649	19,862	59	111	24,323	30	58	55,248	121	253	2,724,471	4,176	8,460
60	33,136	754	1,512	18,530	54	101	22,691	27	54	51,542	111	232	2,541,707	3,828	7,755
65	31,120	696	1,396	17,402	50	94	21,310	25	49	48,406	102	214	2,387,060	3,534	7,158
70	29,392	646	1,296	16,436	46	87	20,127	24	46	45,718	95	199	2,254,505	3,281	6,647
71	29,075	637	1,278	16,259	45	86	19,910	23	45	45,226	94	196	2,230,234	3,235	6,553
72	28,768	629	1,260	16,087	45	84	19,700	23	45	44,747	92	193	2,206,638	3,190	6,462
73	28,468	620	1,243	15,920	44	83	19,495	23	44	44,282	91	191	2,183,688	3,147	6,374
74	28,177	612	1,226	15,757	44	82	19,296	22	43	43,829	90	188	2,161,358	3,104	6,287
75	27,894	603	1,209	15,598	43	81	19,102	22	43	43,388	89	186	2,139,624	3,063	6,204
80	26,584	566	1,134	14,866	40	76	18,204	21	40	41,350	83	174	2,039,104	2,871	5,816
85	25,427	532	1,067	14,219	38	72	17,412	19	38	39,551	78	164	1,950,409	2,702	5,474
90	24,400	503	1,008	13,644	36	68	16,709	18	36	37,952	74	155	1,871,569	2,552	5,170
95	23,480	476	955	13,130	34	64	16,079	17	34	36,522	70	147	1,801,029	2,418	4,898
100	22,652	453	907	12,667	32	61	15,512	16	32	35,234	66	139	1,737,542	2,297	4,653